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AN ANALYSIS OF BANDWIDTH REQUIREMENTS FOR COLLABORATIVE PLANNING

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Any military operation, no matter how large or small requires some level of planning. Planning has become more complicated, requiring interactions across geographical, functional, and organizational boundaries in a more compressed command and control decision cycle. For ships at sea, planning with other units, at sea or on shore, is constrained by the availability of communications bandwidth and limitations of the tools used for real-time interactions. Emerging tools such as audio and video conferencing and shared whiteboard, enable real-time collaboration among dispersed forces. However, these tools are bandwidth "greedy," requiring more than is currently available on many ships. In an effort to determine what amount of bandwidth a ship needs, this thesis used simulation and modeling to experiment with combinations of bandwidth, collaboration tools, number of planners, and network delivery methods. In general, a bandwidth of 128 kbps enables two ships to conduct a video and audio session. Using multicast network delivery, 256 kbps enables a ship to collaborate with five other sites, and at 384 kbps, a ship can conduct a whiteboard with video and audio with up to eight other sites.

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AN ANALYSIS OF BANDWIDTH REQUIREMENTS FOR COLLABORATIVE PLANNING

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ABSTRACT

Any military operation, no matter how large or small requires some level of planning. Planning has become more complicated, requiring more interactions across geographical, functional, and organizational boundaries in a more compressed command and control decision cycle. For ships at sea, conducting planning with other units, at sea or on shore, is constrained by the availability of communications bandwidth and limitations of the tools used for real-time interactions. Emerging tools such as audio and video conferencing and shared whiteboard, enable real time collaboration among dispersed forces, however, these tools are bandwidth "greedy," requiring more than is currently available on many ships. In an effort to determine what amount of bandwidth a ship needs, this thesis used simulation and modeling to experiment with combinations of bandwidth, collaboration tools and the number of planners.

In general, a bandwidth of 128 kbps enables two ships to conduct a video and audio session. Using multicast network delivery, 256 kbps enables a ship to collaborate with five other sites, and at 384 kbps, a ship can conduct a whiteboard with video and audio with up to eight other sites.

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EXECUTIVE SUMMARY

Planning is the act of preparing for future events. Any military operation, no matter how large or small, length of anticipated duration, or how much time is available to prepare, requires some level of planning. In today's environment of increased operational tempo, more widely dispersed forces, and operations in joint or multinational coalition force structures, planning has become more complicated. Planning requires more interactions across geographical, functional, and organizational boundaries and in a more compressed timeframe in order to keep our command and control decision cycle faster than our adversaries. For ships at sea, conducting planning with other units, at sea or on shore, is constrained by the availability of communications bandwidth and limitations of the tools used for real-time interactions.

Emerging products, such as audio and desktop video conferencing, and shared whiteboard, enable geographically dispersed people to collaborate in real-time. Used at sea, these tools provide the ability for planners to share information in a wide variety of formats, in real-time with their counterparts on other ships or ashore. However, these tools are bandwidth "greedy" and require more bandwidth than is currently available on many ships. Any implementation of these tools involves a trade-off decision between the cost of the resource, bandwidth, and the amount of capability desired, such as audio, video, or whiteboard.

How much bandwidth does an amphibious ship need in order to perform collaborative planning? The thesis seeks to provide some insight into this question through the use of a high-level simulation model built using a commercial off-the-shelf product called Extend. Over 170 model runs were executed with various combinations of the three collaboration tool types, the amount of bandwidth, the number of planners involved in a planning session, and the type of network delivery method used. The results of these runs are presented from three different aspects, by

required collaboration capabilities, by bandwidth, or by the number of other planners that can be involved, as follows:

- Minimum collaboration capabilty required by the ship. If, at a minimum, a ship must be able to conduct a video and audio session with one other ship, than at least 128 kbps must be available to each ship. To conduct a whiteboard with audio session, at least 256 kbps must be available. Whiteboard with video and audio requires 384 kbps.

- Bandwidth is limited. If a ship only has 128 kbps available, then the ship will only be able to conduct a video and audio session with one other ship. At 256 kbps, a ship can collaborate via a video and audio session or a whiteboard with audio session with up to two other sites. At 384 kbps, using multicast delivery, a ship will be able to engage up to eight other sites in a whiteboard with audio session.

- Number of planners required in a collaboration session. To collaborate with one other planner a ship requires at least 128 kbps and a session with two other planners, at least 256 kbps. To collaborate with five to eight other planners, at least 384 kbps must be available at the ship and multicast network delivery must be used to ease the bandwidth congestion at the ship.

To ensure flexibility and adaptability to any planning situations a ship may be engaged in, an optimum mix might be to provide at least 256 kbps bandwidth and use multicast network delivery, so the ship can access some combination of the three collaboration capabilities provided by the tools with up to five planning counterparts. Without multicast delivery, at least 384 kbps will be required for three ships to engage in a collaborative planning.

I. INTRODUCTION

A. OVERVIEW

An amphibious operation is an attack launched from the sea by naval and landing forces embarked in ships or craft landing on a hostile shore (Joint Pub 3-02). The amount of communications support required for such an operation exceeds that of any type of naval warfare (Kim and Muehldorf). Planning for a landing is also complex due to the involvement of all types of ships, aircraft, weapons, and units of the Navy and landing forces and the geographic dispersion of supporting forces.

Much of the information shared and analyzed during amphibious landing planning involves the use of maps, charts, and imagery. Ships are limited in the ways they can interact with their planning partners at sea or ashore, and the format of the information does not lend itself to unambiguous discussion over voice circuits or through text messages. Planners left to work independently in different locations on the same plan run the risk of forming separate and distinct interpretations of that plan unless efforts are expended to keep all planners in synchrony.

New communications capabilities are possible with the use of collaboration tools such as audio and video conferencing and whiteboard applications. These tools can provide the means for an Amphibious Ready Group (ARG) or Amphibious Task Force (ATF) at sea to continue to conduct planning with shore-based or other ship organizations and to do it in real-time. However, these tools require higher bandwidths than currently possessed by amphibious ships. SHF bandwidth to the ARG Flagship (LHA/LPD) can range from 256 kbps to 512 kbps, but the other ARG ships are not SHF-capable. All amphibious ships are UHF-capable, which can range from 2.4 kbps to 9.6 kbps.

Several efforts are underway to increase the amount of bandwidth on these ships, and most are focused on point-to-point or Line of Sight communications for use between two ships or a ship and shore-based unit. Three efforts of note are (CPG3, Day):

- Digital Wideband Transmission System (DWTS) which will provide UHF LOS at T1 (1.544 Mbps) from ship to ship and from ship to shore at 144 kbps, 288 kbps or 576 kbps.

- UHF Medium Data Rate (MDR) which will provide 448 kbps.

- Hazeltine, an effort to provide a "network" capability among three ships using radios at 64 kbps.

B. OBJECTIVE

The purpose of this thesis is to determine the bandwidth requirements for collaborative planning by amphibious ships. The approach taken was to identify characteristics of the tools used for collaboration (text chat, audio and video conferencing, whiteboard) and simulate the use of these tools in a network among two to nine planning participants, varying the amount of available bandwidth.

C. METHODOLOGY

To assess the impact that bandwidth has on the use of collaboration tools, a network simulation model was built using Extend, by Imagine That, Inc. To derive the parameters of the model, current information about collaboration tools, their bandwidth requirements and the planning process employed by Amphibious Ready Groups (ARG) was obtained by conducting a literature review, Internet searches, and discussions with personnel at SPAWAR San Diego, COMPHIBGRU THREE, Amphibious Warfare School Pacific, and MITRE. Various combinations of the parameter settings were executed and the model results were assessed against the following selected measures of effectiveness: the average amount of time for text chat, audio, video and whiteboard data to travel between participants. Lengthy travel times degrade the quality of audio and video conferencing.

D. THESIS ORGANIZATION

Chapter II provides an overview of four collaboration tools, text chat, audio conferencing, video conferencing, and whiteboard, with discussion of their limitations and bandwidth requirements. Chapter III presents background on the ARG planning process, such as what information is discussed and when, who is involved, and where planning occurs. A discussion of the Extend model structure and specific parameter settings are contained in Chapter IV, and the results of the model runs are presented in Chapter V. Chapter VI will provide conclusions and recommendations for future work.

II. COLLABORATION TOOLS

A. OVERVIEW

Collaboration tools began to emerge in the early 1990's when faster PCs, increased network and communications bandwidth, and more-capable digital video components brought such capabilities into the realm of possibility and affordability (Garland). This chapter will highlight a few collaboration tools that provide the means for same-time, different-place interactions such as text chat, audio conferencing, whiteboard, and desktop video conferencing. Short descriptions of each tool, applicable standards, general limitations, and the bandwidth required will be presented. The intent is not to elaborate on all the technical details associated with multimedia products and processes but to give a feel for some of the concepts and issues.

B. DEFINITIONS

The following definitions and concepts are common across all collaboration tools and impact how the tools are implemented.

1. Collaboration

The Random House Unabridged Dictionary, Second Edition, 1993, defines collaboration "to work, one with another; cooperate." Cooperate is "to work or act together or jointly for a common purpose or benefit." Collaboration always involves some form of interaction between two or more people and it can occur at any time or at any place. "People who need to collaborate can be in the same team or unit, different parts of an organization, and in different organizations. They can be located anywhere on the globe and in any time zone, but still require the ability to communicate with each other, share information with each other, and coordinate their activities" (DIICOE MCSTWG).

2. Multimedia

As defined in the Dictionary of PC Hardware and Data Communications Terms, by O'Reilly and Associates,1996, multimedia means "Literally 'many media', for example, using sound, pictures, and text to (hopefully) make a more effective, understandable, or memorable presentation or conference."

Multimedia teleconferencing is a combination of technology and applications that allow multiple users in multiple locations to interactively share data, desktop applications, and live video simultaneously. The ability to share materials facilitates communications, brainstorming, decision making, and problem solving. (IMTC)

To support multimedia, networks must provide (O'Reilly):

- *Scalable* bandwidth: New users and new applications require connectivity and the network must support ever-increasing traffic loads.

- Consistent *Quality of Service*: The error rate (usually due to dropped packets), network latency (typically less than 400 ms, round-trip), and network throughput must be selectable (according to the needs of the application) and predictable.

- *Multicast* routing, to efficiently support one-to-many-type traffic.

3. Bandwidth

In general terms, bandwidth has come to mean the number of bits per second (bps) that can be transmitted over various media and is the most significant limiting factor in communications. There are two broad categories of communication channels, circuit-switched and packet-switched, and each has implications for multimedia teleconferencing.

Circuit-switched means that a dedicated path is formed between users and all of the available bandwidth of that channel is for their use only; it is not shared with other users. Collaboration tools get the bandwidth they require and the delivery of information is predictable, without delays. If the full amount of the dedicated bandwidth is not needed during the connection, it is in effect "wasted" since there are no other activities on the circuit to use it. When the communications are complete, the dedicated channel is disestablished and the bandwidth is then available for other sessions. Circuit-switched channels are primarily for point to point communications, and conducting a collaborative session with greater than two sites requires the use of expensive Multipoint Conference Units (MCU). An MCU is a server that establishes and manages real-time distribution of audio, video, and document sharing among several sites. Examples of circuit-switched channels are the telephone system and narrowband Integrated Services Digital Network (ISDN) at 128 Kbps.

Packet-switched channels share their total bandwidth among all the users who want to use it. A user's information is broken into packets and each is labeled with identification, sequence number, and destination. The packets are placed onto a channel and may take differing routes through the network to reach their destination, some arriving earlier than others. The time required for the transit depends upon the number of users on the channel – more users means more packets competing for a finite amount of bandwidth resulting in longer delays. Collaboration tools such as audio and video are sensitive to packets that arrive out of order or experience lengthy delays in arrivals. Examples of packet-switched channels are Local Area Networks, such as 10 Mbps to 100 Mbps Ethernet, and Wide Area Networks, such as Asynchronous Transfer Mode (ATM) at 25 Mbps to 2 Gbps and Frame Relay at 56 Kbps to 1.544 Mbps.

To cope with bandwidth limitations, many collaboration applications provide the ability for users to adjust several parameters of their audio and video sessions.

4. Compression and Decompression (Codec)

The nature of audio or video data is such that it requires large amounts of bits for accurate representation. To conserve the amount of bandwidth used when sending audio or video data, the bits that represent the data are compressed into an even smaller number of bits before transmission using complex algorithms called Codecs. At the receiving end, the bits are decompressed and reconstructed to the original form.

Compression and decompression must occur at extremely fast speeds so as not to interfere with the real time interaction of a collaborative session. Hardware Codecs are extremely fast at performing compression algorithms, but they are also very expensive. Software Codecs are easier to install and rely on the workstation CPU for processing power, not additional hardware. The strain the software Codec puts on the CPU may limit the number or type of applications a user may execute simultaneously during a session. Some Codec implementations are a mix of hardware and software - hardware for compression, which is more computationally intense and needs to be done quickly without introducing delay and software for decompression. (CISCO, Hudson)

Many algorithms have been developed for implementing compression but generally these schemes fall into one of two types (CISCO):

- Lossless. A compression technique that creates compressed files that decompress into exactly the same file as the original. Lossless compression is typically used for executables (applications) and data files for which any change in digital makeup renders the file useless.

- Lossy. This type of compression, used primarily on still image and video image files, creates compressed files that decompress into images that look similar to the original but are different in digital makeup. The "loss" is that several bits of the image are no longer represented but the human eye does not detect this loss.

Interoperability issues frequently arise between collaboration products since many vendors have developed their own proprietary Codec algorithms, which offer a wide range of performance, quality, and cost trade-offs.

5. Latency

Real time interactive applications are sensitive to accumulated delay, known as latency. A network contributes to latency in the following ways (CISCO):

- Propagation Delay. The length of time that information takes to travel the distance of the line. Propagation delay is determined by the speed of light and is not affected by the networking technology in use.

- Transmission Delay. The length of time a packet takes to cross a given media. Determined by the speed of the media and the size of the packet.

- Store and Forward Delay. The length of time an internetworking device (a switch, bridge, or router) takes to send a packet that it has received.

- Processing Delay. The time required by an internetworking device to perform a route lookup, change headers, and other switching tasks. In some cases, the packet may have to be manipulated such as encapsulating it into another packet type.

Variable network delays can cause disruptions in audio or video data, called "jitter." A common technique for minimizing jitter is to buffer the arriving data at the receiving end and then deliver it to the user at a more constant rate.

6. Quality of Service

Two measures of quality of service are the reliability of delivery across a network and the amount of delay experienced. Different types of data have varying degrees of sensitivity to these measures. For example, transferring data files requires more emphasis on reliable delivery than on minimizing delays encountered during the transfer. It is more important that all the bits arrive than whether the file arrives within one second or one minute at its destination. Table 2-1 summarizes data types and their sensitivity to reliable delivery and delay.

	Data	Voice	Video	Image
Delay Sensitive	No	Yes	Yes	No
Reliability Sensitive	Yes	No	Yes/No	Yes

Table 2-1. Data Type Sensitivities (Rettinger).

Delays in voice transmissions can be annoying and frustrating to people involved in a discussion, as it is disruptive to the flow. Studies have shown that people get annoyed when end-to-end audio delays approach 400 milliseconds (ms) and 700 ms to 800 ms is beyond tolerance. Ideal quality of service for a one-way audio stream is considered to be less than 45 ms delay plus variance. Telephone networks are engineered to provide less than 400 milliseconds round-trip latency for the voice signals they handle. Voice is not sensitive to reliability and the occasional missing sounds or syllables can be recovered by the speaker repeating them or deduced by the receiver based upon content. (Brown, Rettinger)

Delays in receiving video can cause movements to appear jumpy. Uncompressed video is more tolerant of lower reliability because the video is transmitted a frame at a time and any frame sent with an error or lost enroute will be replaced by a newly arriving frame. Compressed video is already reduced in the amount of data it contains, so any corruption or loss may not be corrected by subsequent frame updates as the redundancy has been removed. This possibility is corrected by sending out refresh updates - a series

of frames that contain all the video data. Tolerable delay for video can be up to 95 ms delay plus variance. (Brown, Rettinger)

If given a choice in a collaboration session as to whether to experience audio delay or video delay, most people prefer the audio to be delivered as close to real time as possible and will endure a delay in the video even though it will be out of sync with the audio (Isaacs).

7. Standards

To guide the development of collaboration tools that are interoperable, there are several standards which have been ratified by the International Telecommunications Union (ITU). The T.120 series addresses real time data conferencing (audiographics) standards that allow people at multiple locations to conduct normal voice conferences and manipulate still images such as documents, spreadsheets, color graphics, and photographs. (IMTC)

The H.320 series governs the basic concepts of audio, video, and graphical communications by specifying requirements for processing audio and video information, providing common formats for inputs and outputs, and protocols for use of communications links and synchronization of signals. Specifically, H.320 standards address videoconferencing over circuit switched networks, such as Integrated Services Digital Network (ISDN). H.323 extends H.320 video to corporate Intranets, LANs and other packet-switched networks, such as the Internet. H.324 specifies a common method for sharing video, data, and voice simultaneously using high-speed modem connections over a single analog line telephone line. (IMTC)

Since collaboration implies communications with others, using products that support these standards is the single biggest factor towards being able to conduct interoperable collaboration sessions. All parties conducting a collaboration session must use products that support the same standards or the session can not be conducted.

C. TEXT CHAT

1. Description

Text chat is a method by which two or more people can converse in real time by typing their comments on their computers, which are connected via a network. Each person sees the comments typed by the other conversation participants. What you type is what they see. Conversations can be held between two people or up to several hundred people.

Users execute text chat via a *client* program running on their PC's, and designated computers on the network run *server* programs. These servers help manage and transport the messages between clients. Each conversation is called a *channel* and they may be public (where everyone in a channel can see what you type) or private (messages between only two people, who may or may not be on the same channel). The number of members participating in a channel is dynamic - users may join and leave at any time. A channel may also be thought of as a named group of one or more users, which will all receive messages addressed to that channel.

2. Standards

The most common program for text chat is Internet Relay Chat (IRC), which has been around since the late 1980s and is available for download from several Internet sites for several platforms: UNIX, Windows, and Macintosh. IRC consists of various separate networks (or "nets") of IRC servers that allow users to connect to IRC. One of the largest nets is Efnet, the original IRC net, which often has more than 32,000 people participating at once and has more than 12,000 channels, each devoted to a different topic [IRC]. Internet Relay Chat is the Internet Engineering Task Force (IETF) standard for text-based chat (MITRE).

3. Limitations

People can think and talk faster than they can type, so lengthy, meaningful conversations can be difficult to conduct online. There is a maximum user message length of 512 characters (about seven typed lines) so most conversations consist of short comments and requests for information (IRC). Obviously this tool is better suited to share text-based information, not graphics or imagery. Text chat is a good tool for communications across a network when other tools are not available, such as the telephone, video or audio conferencing, or in situations when bandwidth is constrained.

4. Bandwidth Requirements

Of all the collaboration tools, text chat requires the least amount of bandwidth. Messages have a maximum size of 512 characters or, at 8 bits per character, a total of 4096 bits. Increasing the number of participants in a text chat session does not really degrade the network too much since the amount of information sent at a time is so small and not usually sent all at the same time. For example, if three people were in a text chat session, the worst case scenario would be everyone sending a message at the same time. A user sending out 4096 bits while receiving 8192 bits from the other two people (4096 bits each) would have a total of 12,288 bits competing for bandwidth at her workstation.

D. AUDIO CONFERENCING

1. Description

Audio conferencing has traditionally been conducted using the telephone system for performing person-to-person calls or conference calls of greater than 2 people. Audio conferences can be performed across networks with the addition of a microphone,

speakers, a sound card, and a compression-decompression (Codec) algorithm to a personal computer.

The overall process is to digitize your voice's analog signals, compress the digital form, transmit it, then decompress and decode the digital signal at the receiving end - all in real time. Analog to digital conversion basically consists of taking a series of samples of the analog source and representing those samples with a number of bits. The higher the sampling rate and the higher the number of representative bits, the higher the quality of the digitized audio because more information will be available to recreate the original analog source. Some common sampling rates are: 8000 samples per second at eight bits per sample, for telephone quality audio, and 44000 samples per second at 16 bits per sample, for CD quality.

2. Standards

There are several Codecs recommended by the ITU and other public standards listed in Table 2-2. Minimum compliance is to employ G.711.

Codec	Data Rate	Comments
G.711	48, 56, 64 Kbps	(Narrowband) Telephone quality audio.
G.722	48, 56, 64 Kbps	(Wideband) Stereo quality audio.
G.723.1	5.3 and 6.4 Kbps	Speech Coding at very low rates.
G.728	16 Kbps	Optionally lower rate for use in video conferences with limited bandwidth.
G.729	8 Kbps	
GSM	17 Kbps	(Group Speciale Mobile) European Standard for Cellular Telephony.
LPC-10	2.4 kbps	U.S. Federal Standard
CELP	4.8 kbps	(Code Excited Linear Prediction) U. S. Federal Standard

Table 2-2. Audio Codecs (MITRE).

3. Limitations

Audio signals are sensitive to network delays as described earlier. Audio conferencing over a network is typically not done in stand-alone mode. It is usually bundled with whiteboard or video conferencing tools to enable amplifying information to be discussed along with the presentations shown on the computer screen. If all you are going to do is talk, you might as well use the phone; it is easy, cheap, and interoperable.

4. Bandwidth Requirements

Most commonly used measure for audio is a minimum rate of 64 Kbps, based on telephone quality at 8000 samples a second, 8 bits a sample. For CD quality sound, at 44000 samples every second and 16 bits per sample, a "worst case" data rate of 704 Kbps would be required.

Compression can be used to lower these data rates as well as the mode of operation. Full duplex mode of audio is being able to hear and speak at the same time. This uses up more bandwidth since in effect you will have two streams, one in and one out. Half-duplex mode, in which audio occurs in one direction at a time triggered by the person who is speaking, is bandwidth conservative.

As an example, two people conducting an audio conference with telephone quality audio, in full-duplex mode, would require a total of 128 kbps to be available at each person's workstation for 64 kbps audio going out and 64 kbps audio coming in.

E. DESKTOP VIDEO CONFERENCING

1. Description

Desktop video conferencing is the next best thing to being there. No longer confined to the room-based equipment of the 1980s, video is available on your workstation and is almost as easy as using the telephone. Being able to "see" the person "adds or improves the ability to show understanding, forecast responses, give non-verbal information, enhance verbal descriptions, manage pauses and express attitudes" (Isaacs). Video conferencing enables face-to-face interactions with people geographically dispersed, without the expense, waste of time, and inconvenience of traveling.

The process of sending and receiving video over the network is the same as for audio. The analog video signal is digitized, compressed and transmitted across the network, then decompressed and decoded at the receiving end. A workstation will require a digital video camera, a Codec algorithm, and a video capture card, in addition the equipment required for audio: microphone, speakers, and sound card (Glover).

There are two types of video: streaming and real time. Streaming video is pre-recorded video that is stored on servers which is played when requested by a user, such as movies on demand. The other type is real time video where the video source is created while watched, such as video conferencing.

The quality of the video images is influenced by the frame rate at which the video is transmitted, the number of bits used for color depth, and the size of the frame used. Video is actually a series of still pictures presented in sequence at such a fast rate that the human eye perceives continuous motion. Motion pictures achieve this effect with 24 frames per second (fps) and television uses 30 fps. Typical desktop video ranges from 4 fps to 15 fps.

Video, as displayed on your workstation monitor, is made up many picture elements, "pixels", each of which represents a small dot in the overall image. Depending upon the color distinctions required, a pixel can be represented by several bits such as 16

bits for over 65,000 colors, or a few bits, such as eight for 256 colors. Sixteen shades of gray can be represented in four bits or in eight bits for a finer resolution.

There are several frame sizes that can be used. Full screen is 640 pixels by 480 pixels, quarter screen is 320 pixels by 240 pixels, and sixteenth screen is 160 pixels by 120 pixels. Standards-based frame sizes are the Common Intermediate Format (CIF) of 352 pixels by 288 pixels, and the Quarter CIF (QCIF) which is 176 pixels by 144 pixels (Zeichick).

2. Standards

Video is by far the most bandwidth demanding application of all the collaboration tools, and compression technology is the single biggest factor that has enabled video to occur at the desktop. It is also where interoperability between products becomes an issue. Each participant in a video session must be using the same compression algorithms in order for the session to even occur. A good detailed discussion of video compression is presented in Mark Glover's Master's Thesis (Glover).

Table 2-3 lists additional standards not mentioned earlier in Section B.

Standard	Description
H.261	Compression for rates > 64 Kbps; defines CIF, QCIF
H.263	Compression for rates < 64 Kbps
H.225.0, H.245	Communications, signaling, and control for conferences on packet-switched networks
MPEG-1	(Motion Picture Expert Group) Compression to fit into 1.5 Mbps bandwidth
MPEG-2	For rates between 4 and 9 Mbps
MPEG-4	Low bit-rate compression for rates < 64 Kbps
Native NV	Xerox PARC for higher bit rates
CellB	Sun Microsystems for higher bit rates
CUSM	Cornell CUSeeMe Gray for lower bit rates
White Pines Color	White Pines for 24 bit color over lower bit rates

Table 2-3. Video Compression Standards (MITRE).

3. Limitations

The type of information that can be conveyed by video is generally limited to what can be shared by seeing and hearing a person talking and gesturing. Holding up charts or slides in front of the camera for viewing by other session participants is ineffective - the resolution will not be good enough for the documents to be read. Other than faxing or emailing documents out prior to a video session, other collaboration tools such as whiteboard or shared applications can be used when there are documents to discuss. Many video products come bundled with these capabilities and their use requires additional bandwidth.

The limit on the number of video windows that can be displayed on your monitor simultaneously can be anywhere from two to twelve or more, with workstation performance degrading as more video windows are displayed.

4. Bandwidth Requirements

Acceptable quality is frequently determined in the eye of the viewer and will be constrained by the available bandwidth. Most products enable the user to scale the number of frames per second, set a limit on the amount of bandwidth to be used, or set the amount of compression to perform. Video can be compressed up to 20:1 and still deliver a reasonable picture (CISCO).

Another technique to conserve bandwidth is called motion compensation, in which only the bits in a video frame which represent movement since the last frame are compressed and transmitted. For example, in a video of a seated person talking, only the bits associated with the movement of the person's face, and the occasional head or hand movement is transmitted. For the most part, the rest of the scene in the video is static and the bits would not be refreshed as often.

Table 2-4 gives a feel for how many bits are required for one second of video for two frame sizes (CIF, QCIF), using four bits per pixel (for 16 shades of gray), and varying frames per second from 4 fps to 15 fps. The numbers derived in the frame compression

column were simply calculated to give an idea of what a 20:1 compression ratio would be and they are not the exact numbers a Codec algorithm might derive for a 20:1 ratio setting.

Frame Size	Total pixels/frame	Number of gray bits	Total bits/frame	Frame Compression (20:1)	Frame rate (fps)	Total Bits for one second of Video
CIF (352 X 288)	101,376	4	405,504	20275	4	81,100
CIF (352 X 288)	101,376	4	405,504	20275	15	304,140
QCIF (176 X 144)	25,344	4	101,376	5069	4	20,276
QCIF (176 X 144)	25,344	4	101,376	5069	15	76,035

Table 2-4. Total Bits for One Second of Video (Author).

Based on Table 2-4, a minimum of about 20 Kbps would be needed for a video conference transmitting at 4 frames per second. At this frame rate, any movements at the source may appear jumpy to the receiver, but a meaningful interaction is still possible. Now, add 64 Kbps for audio and the total bandwidth required would be about 84 Kbps for each participant. In a conference with two people, each workstation would need at least 168 Kbps: 84 Kbps for outgoing video and audio and 84 Kbps for the incoming video and audio.

F. WHITEBOARD

1. Description

Conference rooms usually have a whiteboard or blackboard present for use during meetings to draw diagrams or charts, list issues, or record action items. Electronic whiteboards carry this same concept to your computer screen and across the network. A

picture is displayed as a backdrop and each participant in the session uses a uniquely colored marker to gesture, point, draw, or type text on top of the picture in a non-destructive mode. What you see on your screen is what everyone else sees and shrinking or scrolling the picture will change everyone's view.

The displayed pictures can be maps, charts, imagery, still video, or briefing slides which are imported or captured from other applications and pasted or "snapped" into the whiteboard area. Any participant can snap in a new backdrop picture during the whiteboard session. Completed whiteboards with annotations can be exported and saved for later reference by any of the participants.

Whiteboard combined with audio has been called the "premier collaboration tool" due to the ease at which a wide range of information can be shared among geographically dispersed people in real time from a network workstation (MITRE).

2. Standards

ITU T.126 defines a protocol for viewing and annotating still images transmitted between two or more applications, often referred to as document conferencing or shared white board.

3. Limitations

The number of participants should be kept low to ensure a productive session. In fact, many products have limitations on the number of uniquely colored markers that are available, ranging from eight to 15. Whiteboard is best when used with text chat or audio to enable participants to provide running commentary about the annotations they place on the displayed pictures. This will increase the bandwidth required for the collaborative session.

Interoperability issues between products exist due to the different ways vendors implement the operations the annotation tools perform on the picture backdrops and how the whiteboard session is established and controlled.

Not all file types can be imported or exported. Many products can not import Graphical Interchange Format (GIF) files or export to National Imagery Transmission Format Standard (NITFS) (MITRE).

4. Bandwidth Requirements

A whiteboard session is bursty in nature, as there is an increase in the bandwidth required when a backdrop picture is initially distributed to all participants. The size of the burst depends on the type of picture transmitted, whether it is a chart, map, briefing slide, or still image. Table 2- 5 provides examples of relative sizes of document types that may be used in whiteboard sessions. The annotations that occur on the backdrop picture use relatively low amounts of bandwidth, about 2.4 kbps per participant (MITRE).

In general, a whiteboard session will tend to use less bandwidth than the accompanying audio (Floyd).

	Picture	Size (pixels by pixels)	Total Bytes	Total Bits (8 bits/byte)	Number of bits with compression (20:1)
1	Weather - Current Satellite View (Korea)	384 X 256	196824	1574592	78730
2	Weather - Forecast Map	400 X 300	240216	1921728	96086
3	Imagery (West Baghdad)	1119 X 739	1648856	13190848	659542
4	Hydrographic Chart (Montserrat)	514 X 692	987608	7900864	395043
5	Topographical Map 1:20,000 Scale	1087 X 658	1432024	11456192	572810
6	MS Powerpoint Slide (graphics)		118000	944000	47200
7	MS Powerpoint Slide (text)		72000	576000	28800

Table 2- 5. Picture Bit Sizes (NIMA, Author).

G. METHOD OF NETWORK DELIVERY

Communication among human beings can occur in these formats: person to person, from one speaker to a large audience, and from many people to many people as in a meeting or via a bulletin board. Collaboration tools have evolved and enable humans to continue these forms of communications over computer networks. Many computer communications are point to point, such as email from sender to receiver, file downloads, web accesses, clients accessing servers to run applications. Many to many or "multipoint" communications can take place with the use any of the collaboration tools described in this chapter, but these applications are bandwidth intensive. Compression is one technique used to conserve bandwidth. Another approach is to streamline delivery across networks. There are three general methods for multipoint delivery: Unicast, Broadcast, and Multicast. Figures 2-1, 2-2, and 2-3 graphically describe these methods.

1. Unicast

In this method, the sender's application transmits one copy of each packet of information to each conference participant using individual addresses. This method does not scale well to large groups and wastes bandwidth since multiple copies may travel shared paths through the network. The burden in this method is on the sender's host computer, which must send out the same number of information packet copies as the number of intended receivers. Delays in transmission will occur when the sender is bandwidth limited.

In a collaborative session, the sender may be sending out audio and/or video streams to two other participants, as well as receiving audio and/or video streams from the two participants. Therefore, in an audio conference using 64 kbps audio, the sender would be sending 128 kbps and receiving 128 kbps. A total of 256 kbps must be available at the sender's workstation.

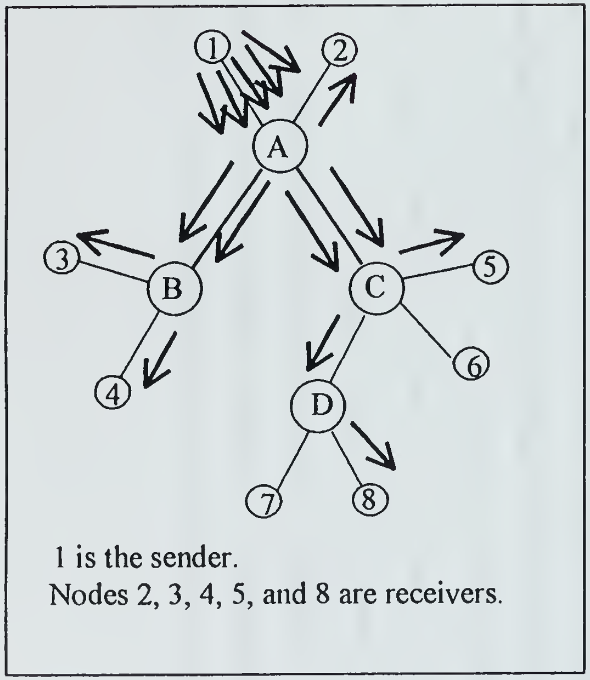


Figure 2-1. Unicast Delivery

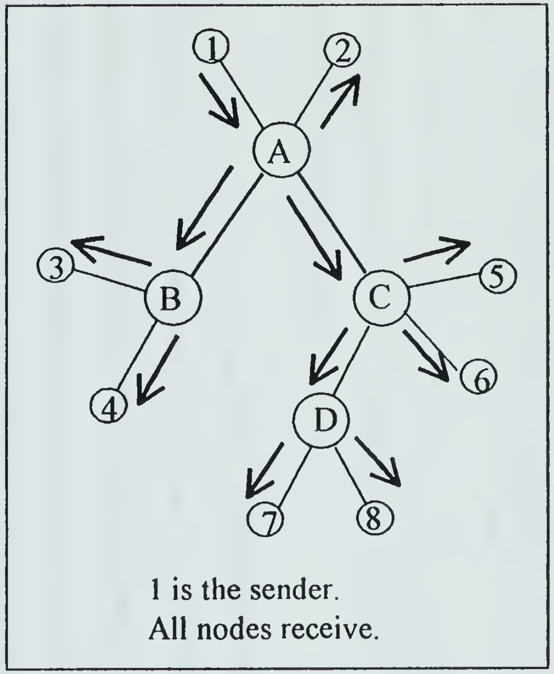


Figure 2-2. Broadcast Delivery

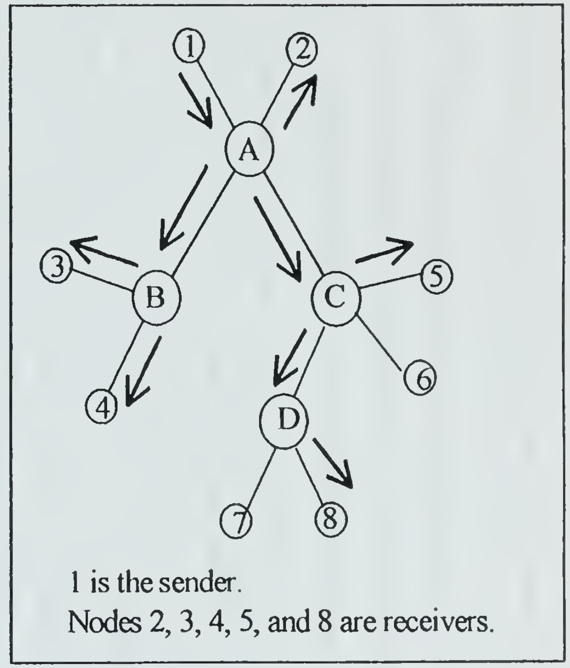


Figure 2-3. Multicast Delivery

2. Broadcast

A sender's application transmits one copy of each packet of information using a reserved address for broadcast traffic. The information is delivered to everyone on the network regardless of the need for the information. Those nodes that do not need the information just discard it. This method is extremely wasteful of bandwidth in situations where only a small number of nodes want to receive the information. In this case, the bandwidth burden is placed on the network itself and its available capacity.

For use in a collaborative session, video could be broadcast from the site where the speaker is out to the other session participants, thereby reducing the number of outgoing streams from the sender but the communication will be one-way only. Broadcast transmission is also good for distributing static information such as pictures for whiteboard sessions.

3. Multicast

This method enables the sender to send one copy of each packet of information using a reserved address designated for nodes that want to receive the information. As the packets traverse the network, multicast routers are on the lookout for this special address on behalf of interested nodes in their subnets. If a multicast router has no nodes interested in the packets, it forwards the packets on to the next hop. If there is interest, the multicast router will replicate the number of copies needed and deliver the packets to those specific nodes within its subnet. For an in-depth technical discussion of IP Multicast, refer to (Glover). In general, overall network bandwidth use is minimized since the number of duplicate network paths the packets take is reduced. However, store and forward or processing delays may be increased at the multicast routers.

This method also significantly reduces the amount of bandwidth required at a sender's workstation. For example, in the audio conference as described above, with multicast delivery, the sender would only send out 64 kbps of audio for delivery to two

other participants and receive in 128 kbps (two audio streams from other participants) for a total of 192 kbps.

H. SPECIFIC APPLICATIONS

The Defense Information Infrastructure Common Operating Environment Multimedia/Collaborative Services Technical Working Group (DII COE MCSTWG) has been established as part of the DII COE and is tasked to define a common core of required capabilities for collaboration software services. Appendix A contains lists of these requirements for audio, video, and whiteboard applications.

This working group also conducted an evaluation of audio, video, and whiteboard commercial off the shelf products in 1997, the results of which are contained in Appendix B. In general, many of the products currently available provide point to point sessions or multipoint sessions through the use of Multipoint Conference Servers; multicast delivery has not yet been widely implemented.

I. SUMMARY

Collaboration tools offer many new communication capabilities via computer networks. Each tool has varying uses and benefits, but no one tool can do it all. The nature of the information to be shared and the available bandwidth will determine which tool will be effective. Possessing a variety of these tools will provide greater flexibility and adaptability in situations when collaboration with geographically dispersed people is required.

III. AMPHIBIOUS PLANNING

A. OVERVIEW

The planning process, the participants and the types of information discussed during planning, is described in this chapter and provides the basis for the operational scenario of the simulation model built to analyze bandwidth requirements required for collaborative planning by amphibious ships.

B. ORGANIZATION

Amphibious ships regularly conduct their operational deployments as an Amphibious Ready Group (ARG) which consists of three ships (EWTG):

- Amphibious Assault General Purpose Ship (LHA) or Multi-Purpose Ship (LHD). This ship is the lead or "flagship" of the ARG and will have the Amphibious Squadron (PHIBRON) and Marine Expeditionary Unit (MEU) Staffs embarked. The mission of the ship is to embark, deploy, and land elements of a landing force in an assault by helicopters, landing craft and amphibian vehicles.

- Amphibious Transport Dock (LPD) ship to transport and land troops and their equipment and supplies by means of embarked landing craft and amphibious vehicles augmented by helicopter lift.

- Amphibious Dock Landing (LSD) ship. This ship transports and lands troops, equipment and supplies of the landing force by means of embarked, pre-loaded landing craft and amphibian vehicles. Usually acts as the Landing Craft, Air Cushioned (LCAC) control ship in an amphibious operation.

At any time during an ARG deployment, one or two of the ships may be temporarily detached to perform a specific mission, such as advance force preparations. This configuration is called a "Split ARG" and the operating distances are relative and can range anywhere within the ARG's assigned geographical theater of operations. (Clark)

When an Initiating Directive order is issued the planning phase of an amphibious operation is started and the ARG is transitioned into an Amphibious Task Force (ATF) and Landing Force (LF) for the purpose of conducting an amphibious operation. The ARG forces are supplemented to form an ATF composed of a primary control ship, a secondary control ship, landing craft, transport ships, a screen and surface action group, minesweepers, and AAW/fire support/ASW ships. The senior Navy officer is designated the Commander, Amphibious Task Force (CATF). The Landing Force is commanded by the senior landing force officer, usually a Marine Corps officer but could be an Army Officer, and is composed of a Battalion Landing Team and Regimental Landing Team. Other forces may include the U. S. Air Force, garrison forces, and base construction forces. The CATF and CLF are positioned onboard the ATF flagship, an LHA or LHD, and it is onboard this ship where the primary planning for the operation occurs. (Kim, EWTG)

C. OPERATIONS

In general, there are four types of amphibious operations and the conduct of each operation is executed following a five-phase sequence of events.

1. Types

Amphibious operations can be categorized as follows (Joint Pub 3-02):

- Amphibious Assault, which involves establishing a force on a hostile or potentially hostile shore.

- Amphibious Demonstration. An operation using a show of force meant to deceive the enemy into executing an unfavorable course of action to its own forces.

- Amphibious Raid. An operation which involves a swift incursion into or a temporary occupation of an objective prior to a planned withdrawal. Raids are conducted to inflict loss or damage, secure information, create a diversion, capture or evacuate individuals and/or material, and execute deliberate deception operations. Non-combatant Evacuation Operations (NEO) is a type of Amphibious Raid.

- Amphibious Withdrawal to remove forces from hostile or potentially hostile shore to sea in naval ships or craft.

2. Phases

Amphibious operations follow a well-defined sequence of events organized into five phases:

- Planning. Starts when an Initiating Directive order is issued to the Commander, Amphibious Task Force (CATF) and is done continously throughout the operation. Planning is done in parallel and concurrently among the staffs of the CATF, CLF, and other participating forces. So much planning must occur that Joint Pub 3-02 states that the nature of the planning:

> favors the assembly of commanders and staffs of corresponding echelons in the same locality. If such arrangement is not practicable, the exchange of liaison officers qualified to perform essential planning is necessary.

- Embarkation. Period of time in which the forces, with their equipment and supplies, embark onto their assigned shipping.

- Rehearsal. The perspective operation is rehearsed for the purposes of testing plans, timing, combat readiness, testing communications, and ensuring all participants are familiar with the plan.

- Movement. During this period, the various elements of the ATF move to the points of embarkation to the Amphibious Objective Area, and this phase is completed when all ATF forces arrive at their assigned positions.

- Assault. The timeframe between the arrival of the major assault forces of the ATF in the landing area to the accomplishment of the ATF mission.

D. PLANNING PROCESS

There are two types of processes employed – deliberate and rapid response; the primary difference between the two is the time allocated to perform the planning. Deliberate planning occurs continuously within an ARG to maintain a state of readiness and ability to quickly respond to any contingencies that may flair up during their deployments. Rapid Response planning is the deliberate planning process compressed into a six hour evolution.

1. Deliberate Planning

There are 15 deliberate planning steps (EWTG):

1. Receipt of the mission via Initiating Directive by the CATF and CLF.

2. Mission Analysis. Determine the Higher Commander's intent, the purpose, the tasks required to achieve the purpose, and any tactical, political, time and space, weather, or rules of engagement limitations. Develop assumptions about friendly and enemy force capabilities and identify critical vulnerabilities, capabilities, and requirements.

3. Determine information requirements with regards to intelligence and friendly forces required by the Commander for the successful execution of the operation. The information may be obtained from sources such as maps, charts, imagery, ground sensors, enemy signal communications, enemy documents, intelligence documents, and weather forecasts.

4. Initial Staff Orientation. The CATF and CLF will each conduct separate meetings with their staffs who are called upon to speak in their area of expertise with respect to the operation and contribute knowledge in such as areas as terrain, hydrography, the area of operations, enemy capabilities, available forces, and logistics support.

5. Commander's Planning Guidance. The CATF and CLF staffs get together to discuss the operation and the initial basic decisions that must be made before detailed planning can proceed. The decisions are: ATF general course of action, objectives, the Landing Force mission, objectives and concept of operations, the landing site, beachheads and landing areas, helicopter landing zones, and the D-Day and H-Hour.

6. CATF and CLF Commanders issue planning directives that provide the schedule and the instructions covering the planning process execution.

7. CATF and CLF Commanders provide initial planning guidance, their philosophies and issues regarding the operation and the overall plan to their staffs to assist in focusing course of action development.

8. Develop courses of action for accomplishing the mission via collaboration between the CATF and CLF staffs.

9. CATF and CLF commanders are briefed on a range of proposed courses of action and approve a general set of potential actions.

10. The staffs conduct estimates of supportability of the general set of selected courses of action using the criteria of suitability, feasibility, acceptability, and completeness.

11. Commander's Estimate document is prepared.

12. Development of the Concept of Operations which describes how the commander intends to use the forces at hand to accomplish the mission.

13. Preparation of detailed plans on selected course of action.

14. Approval of the plan by the Commander.

15. Continued supervision by the Commander and Staff to ensure the plan is updated until required or executed as intended.

2. Rapid Response Planning

When amphibious units are required to conduct a rapid execution of certain missions, the planning process is compressed into six hours, and emphasis is placed on using verbal briefs with standardized slide formats vice generating written documents. The six hours are allocated as follows:

- First hour and 30 minutes is spent on the first 12 steps of the deliberate planning process listed previously. Primary planning location is onboard the ATF Flagship and conducted by a Crisis Action Team (CAT). The CAT consists of the PHIBRON Commanding Officer, N2, N3, N4, N5, and N6; the MEU Commanding Officer, Executive Officer, S2, S3, S4, S6, and Staff Judge Advocate; a meteorologist, major subordinate elements of the Landing Force, and any other individuals the CATF or CLF designate. During this timeframe, various information is shared: the meteorologist provides a weather brief; N2 /S2 provides intelligence, enemy order of battle, threat and country briefs; N3/S3 discuss landing areas with maps and charts; the Staff Judge Advocate covers the Rules of Engagement; N3/S3 briefs the status of friendly forces; and the PHIBRON and MEU commanders deliver their initial planning guidance.

- One hour and 30 minutes is spent developing detailed plans.

- One hour is spent conducting a confirmation brief, which covers the commander's approval of the plan the concept of operations. The execution order is issued verbally.

- Last two hours are used to brief the troops, complete readiness checklists, and to conduct drills and rehearsals.

E. PARTICIPANTS

Currently, many of the primary planning participants are organic to the ATF and located onboard the flagship. If not already onboard, the appropriate personnel are delivered via helicopter to the flagship in order to conduct face-to-face meetings. If representation is needed at the Joint Task Force level, ATF liaison officers are placed onboard the JTF Command ship.

Emphasis on "joint" (more the one Service is involved) or "combined" (forces other than U.S. only are also participating) operations in response to global contingencies only serves to increase the necessity of collaboration and coordination by the ATF or ARG with outside organizations. Planning must be conducted across Services or Combatant command staffs and with other countries' staffs to compose situation assessments, develop courses of action, and to coordinate resources. Additional expertise may be required from outside organizations, such as a Joint Intelligence Center, National Imagery and Mapping Agency (NIMA), a weather center, Modeling and Simulation centers for course of action analysis, and from other federal agencies such as the State or Commerce Departments, in order to plan an amphibious operation.

IV. MODEL SETUP

A. OVERVIEW

As a general representation of collaborative planning conducted by an Amphibious Ready Group (ARG), a nine node, three router network was built and the flow of audio, video, and whiteboard information among the nodes was simulated. This chapter will provide details on the simulation modeling tool used, the operational scenario considered, how the collaborative sessions were derived as well as other model parameters, and the type and number of model runs conducted.

B. SIMULATION MODELING TOOL

An object-oriented modeling program developed by Imagine That, Inc., called Extend, was used to build a nine node, three router network. Extend can be purchased for under $1000.00. Minimum system requirements include:

- Windows 3.1+, 95, or NT 4.0+
- 486 or Pentium-type processor with at least 16 MB RAM and 24 MB hard disk space

The specific machine used was a Gateway 2000, Pentium II 300 MHz processor, with 32 Megabytes RAM, two-gigabyte hard drive and Windows 95 operating system. Minor problems were experienced with an Extend "out of memory" error that prevented some model runs from being simulated for the desired amount of time. The affected model runs are pointed out in Section E of this chapter.

C. OPERATIONAL SCENARIO

The operational backdrop for the network modeled was loosely based upon the amphibious planning process used by an ARG for planning a landing. The types of information most likely to be shared and the number of participants involved during planning were derived from the material presented in Chapter III. Current planning practices involve interactions among personnel primarily located on the ARG Flagship, which can be considered as one node in a network. In the simulation model, a range of locations is used, from two to nine nodes, to portray planning in a more distributed environment.

D. MODEL PARAMETERS

The objective of the simulation model was to analyze various combinations of bandwidth, type of collaboration session, network delivery method, and number of session participants, in an effort to derive a desirable bandwidth for collaborative planning. There were four significant parameters used in the model and their descriptions follow.

1. Bandwidth

Three bandwidth settings were used: 128 kbps, 256 kbps, and 384 kbps, which were derived from the matrix listed in Appendix C. All collaboration participants were assumed to have the same amount available. Varying the bandwidth amounts among the network nodes was not simulated. Collaboration tools are used to perform communications in real-time. Possessing a higher bandwidth provides no speed advantage over a lesser-equipped site since both sites are communicating together, at the same time. The site with higher bandwidth will actually be constrained to operate at the lower bandwidth level of the least capable participant, so all nodes in the model were modeled with the same amount.

2. Number of Collaboration Participants

Two, three, six, and nine nodes were used to simulate communications among two or three ships in an ARG and the ARG with three or six other sites. These other sites represented a Carrier Battle Group or shored-based sites such as support elements for landing team, weather centers or intelligence centers, Fleet Staffs, and other Services or government agencies, any one of which may play a part during the collaborative planning process being conducted by the ARG.

3. Network Delivery Method

Two delivery methods were simulated: Unicast and Multicast, which were described in Chapter II. Maximum node participation was assumed in both methods. In a nine node Unicast scenario, a node would send out eight individual text chat, audio, video or whiteboard bit streams destined for the eight other nodes. In a nine node Multicast scenario, a node would send out one text chat, audio, video, or whiteboard bit stream and the routers would replicate and route the bit streams to reach the eight other nodes.

The specific details of packet delivery, losses and retransmissions and various types of routing protocols were not modeled. The high level effect of modeling these two delivery methods was to stress the bandwidth available at a node as the node attempted to send out the required number of audio and video streams to other nodes participating in a collaborative session.

4. Collaboration Sessions

The exact nature of the information to be discussed at any particular time during a planning session will not always be known or the same each time planning is conducted. Fortunately, the information to be shared during a collaboration session does not have to be modeled explicitly. Each collaboration tool and its use in combination with others

provides the means to transport the planning information across the network, and it is the capacities of these tools that can be modeled. The following paragraphs describe the 13 different collaboration sessions used in the model and how they were derived.

a. Text Chat

A generic message size was set at 100 words. Assuming an average of five characters per word and using eight bits per character, the text chat message size was set at 4000 bits. For a text chat collaborative session it was assumed that each node would send out a message every ½ minute and more than one node could put out a message at a time. The nodes did not have to take turns or wait for messages for other nodes to arrive prior to sending out any messages.

b. Audio Conferencing

Full duplex mode was used so each node could hear and speak simultaneously. Nodes did not have to take turns to speak. Using rates derived from the matrix in Appendix C, two sessions were built:

- Low rate audio of 14.4 kbps.
- High rate audio of 64 kbps.

c. Video Conferencing

Video Conferencing was not done in stand-alone mode, all sessions included audio. As in the audio conference sessions, audio was in full-duplex mode and nodes did not have to take turns to speak. All nodes could see video and hear audio from each of the other participant nodes simultaneously. Video was based on the QCIF frame size of 176 pixels by 144 pixels, grayscale with four bits per pixel, frame compression rate of 20:1, and a low rate of 4 frames per second (fps) and a high rate of 15 fps. Table 2-4 shows the bit sizes derived for one second of video with these characteristics. The

resulting combinations of low audio and video with high audio and video generated four video conference collaborative sessions:

- Video at 4 fps and Audio at 14.4 kbps, for a total of 34,676 bits per second.
- Video at 4 fps and Audio at 64 kbps, for a total of 84,276 bits per second.
- Video at 15 fps and Audio at 14.4 kbps, for a total of 90,435 bits per second.
- Video at 15 fps and Audio at 64 kbps, for a total of 140,035 bits per second.

d. Whiteboard

Whiteboard sessions tend to be bursty in nature as the pictures for backdrops are initially sent to all participants then displayed for a period of time to enable annotations and discussion. During a session, it was assumed that a single node would transmit all whiteboard pictures to each of the other nodes. All nodes were sending audio and video to the other nodes while waiting for the whiteboard pictures to arrive. In a collaborative session, productive discussions could continue during this waiting period while the whiteboard backdrop pictures are updated. The receiving nodes could not begin annotations until the picture had been received and then the nodes took turns to annotate. For example, in a three node scenario, each node would have to wait two time steps before sending its annotation bit stream of 2.4 kbps. Picture 5, the topographical map consisting of 572,810 bits was selected from Table 2-5 and used as the picture transmitted in the whiteboard session. This map is a good example of what might be displayed during an Amphibious Landing collaborative planning session. Like video conferencing, whiteboard is typically not done alone – it is usually accompanied by audio or video and audio together. Whiteboard combined with the various audio and video rates resulted in six sessions:

- Whiteboard (Wb) and Audio at 14.4 kbps.
- Wb and Audio at 64 kbps.
- Wb and Video at 4 fps and Audio at 14.4 kbps.
- Wb and Video at 4 fps and Audio at 64 kbps.
- Wb and Video at 15 fps and Audio at 14.4 kbps.
- Wb and Video at 15 fps and Audio at 64 kbps.

E. MODEL RUNS

Over 170 different variations of the basic model were executed. A discussion of the Extend model structures that were built, the measure of effectiveness used and the various run combinations are provided in the following paragraphs.

1. Basic Model Structures

The node and router structures used in the model will be described and are shown in Appendix D. These basic structures were then used as building blocks and replicated as needed for a six node or nine node network model. Storage requirements varied from 1,176 Kbytes to store a two node model file to 4,200 Kbytes for a nine node model file.

a. Node Structure

Each node sends out text chat, audio, or video messages containing the number of bits representing the specific collaborative session being simulated. Only one node sends out whiteboard message bits. Each node also receives text chat, audio, video messages from other nodes and receives whiteboard messages from one designated node. Time Division Multiple Access (TDMA) mode, using a clock step of 2 milliseconds, was

used to alternately allow designated outgoing messages out from the node to the router and allow incoming messages in from the router to the node. After passing the TDMA gate, all messages are placed into a common first-in, first-out queue. No priorities were assigned based on the type of message – each is handled on a first-come, first-served basis. A transmission delay is then calculated using the bit size of the message divided by the amount of bandwidth available at the node to determine the amount of time required to send or receive a message. After the delay, outgoing messages are sent to the router and incoming messages are sorted and stored by source node.

b. Router Structure

A router has three nodes in its subnet. A message destined for a node within a router's subnet is sent directly to that node by the router. A messagedestined for a node in another subnet is sent to the router serving that subnet. In Unicast delivery mode, the router simply executes a decision tree to decide which subnet nodes or routers are to receive the message and forwards the message to those destinations. In Multicast delivery mode, a router replicates the message for delivery to its subnet nodes and forwards copies of the message to the other routers. No delays were simulated for any processing which occurs at the routers or for the transmission time required for messages to reach the other routers. In general, the differences between the processing delays induced by a regular router and by a multicast router are negligible (Brutzman, Macker, Novotny). The simulation model was built to see how limiting the bandwidth is at the node and not throughout the network.

2. Measure of Effectiveness

For collaborative sessions to be viable, the amount of delay in receiving audio bit streams must be at least under 500 milliseconds and video must be at least under 95 milliseconds for reasons described in Chapter II. The quality of service for video is more

subjective than audio and video frame rates that simply provide an indication of presence, not movement, at other sites may be acceptable and not necessarily take away from the success of a collaborative session. Therefore, more emphasis was placed on using 500 milliseconds or less as an acceptable level of delay for the amount of time for a text chat, audio, video message to leave one node and arrive at another node. Whiteboard messages tended to take longer than 500 milliseconds and delays are a direct factor of the size of the picture and the amount of bandwidth available to transmit and receive the picture. Measurements were taken separately for whiteboard simply to record the amount of delay that occurred in the different parameter combinations. Within the Extend models, outgoing messages were tagged as soon as they were generated at a node and their arrival times at the destination nodes were measured. Measurements were taken within a subnet and across to other subnets as follows:

- Two node scenario. Node 1 to node 2 and node 2 to node 1 for text chat, audio, and video. Whiteboard from node 1 to node 2 only.

- Three node scenario. Node 1 to node 2, node 2 to node 3, and node 3 to node 1 for text chat, audio, and video. Whiteboard from node 1 to node 2 and node 3.

- Six node scenario. Node 1 to node 6, node 2 to node 3, and node 6 to node 1 for text chat, audio, and video. Whiteboard from node 1 to node 3 and node 6.

- Nine node scenario. Node 1 to node 9, node 2 to node 3, node 6 to node 1 for text chat, audio, and video. Whiteboard from node 1 to node 3, node 6, and node 9.

3. Simulation Run Time

A simulation run time of 100 seconds was selected. Extend required approximately three minutes to execute a two node model, four minutes for a three node model, 11 minutes for a six node model and 23 minutes to execute a nine node model.

Other simulation run times were tried: 180 seconds, which took approximately 26 minutes for a six node scenario to execute, 240 seconds which took 33 minutes, and 300 seconds which took 40 minutes to execute. The measured delays from models executed with the longer simulated run times were compared to those captured in model runs for 100 seconds and no significant differences were noted. The delays appeared to consistently occur among the nodes in similar patterns and at a similar ratios, so 100 seconds was selected as the simulation run time for all models.

For the majority of the runs executed, 100 seconds was more than ample time to get text chat, audio, video and whiteboard messages delivered among the nodes. Messages that took longer than 100 seconds were well beyond the acceptable range as described previously.

F. RUN COMBINATIONS

With the number of parameters described in Section D above, many run combinations were possible. The strategy to reduce the number of runs yet execute some meaningful combinations was to first run combinations at each end of the node spectrum, three and nine nodes, and establish some "baseline" runs. The next step was to examine the run results against the selected measure of effectiveness and identify those combinations that were successful. These runs became the "focused" runs and the parameters were further modified. "Special" runs were executed for a high-level look at a point-to-point collaboration scenario and two different locations for a multicast router – on a satellite or at a shore location. Appendix E contains a matrix of the various model parameter combinations that were executed.

1. Baseline Runs

The parameters used were three and nine nodes, 128 and 384 kbps, Unicast and Multicast delivery, and all 13 different collaborative sessions. The various combinations resulted in a total of 104 runs executed.

Difficulties were encountered with runs that tended to be at the high end for stressing the model: 9 nodes, 128 kbps, Unicast delivery, and collaborative sessions with whiteboard, video and audio combinations. At this bandwidth, many nodes did not receive any whiteboard, video or audio messages from some of the other nodes during the specified simulation run time of 100 seconds. A larger simulation run time of 180 was selected and some nodes still did not receive messages. A run time of 240 seconds was then used and Extend ran out of memory for building arrays used to maintain state information about the model. As a result, several of the nine node runs did not generate any data for the measure of effectiveness – the amount of time for a message from one node to arrive at another node. Examination of the data that was collected for delivery times to other nodes revealed that the messages in those affected nine node runs would have been far beyond the acceptable range for audio or video. The measured delays recorded for the affected nine node runs were set to 100 seconds to reflect a "maxed out" state for those runs. This clearly sets the affected runs apart from the other successful runs and is reflected in the graphs presented in Chapter V.

2. Focused Runs

Three collaborative session types were selected from the baseline runs: video at 4 fps and audio at 14.4 kbps, whiteboard with audio at 14.4 kbps, and whiteboard with video at 4 fps and audio at 14.4 kbps. These session types represent the spectrum of capabilities that are offered by collaboration tools, and the rates selected show the most promise for message deliveries with the acceptable delay of 500 milliseconds.

New runs were generated using the parameters: two, three, six, and nine nodes, bandwidths of 128, 256, and 384 kbps, Unicast and Multicast delivery methods, and the three collaborative session types mentioned above. The various combinations resulted in a total of 72 runs executed.

3. Special Runs

These additional 18 runs were constructed to examine specific aspects in an amphibious planning scenario, such as point-to-point collaboration between two ships in Line of Sight (LOS) mode and the effect of location of the multicast router on message delays for a three ship ARG. Two locations of a multicast router were simulated – one onboard a geostationary satellite using a 240 millisecond round-trip propagation delay and the other via a geostationary satellite link to a shored-based router located at a facility such as a Naval Computer and Telecommunications Area Master Station (NCTAMS). In both multicast router scenarios a 1200 millisecond generic router processing delay was implemented (O'Reilly).

G. SUMMARY

An overall representation of collaboration planning conducted by an Amphibious Ready Group (ARG) was built from the aspect of the collaboration tools available and the data rates required for their viable use. Several combinations of collaboration tools, bandwidths, participants, and network delivery methods were executed via a simulation tool in an effort to assess which combinations showed more potential for success. No delays associated with protocols, routers or network congestion were simulated. In effect, the "best case" for text chat, audio, video, and whiteboard message delivery was simulated which only served to highlight the impact that a planning participant's available bandwidth has on the conduct of a collaborative session.

V. MODEL RESULTS

A. OVERVIEW

Over 170 model runs were executed in an effort to provide some insight into the question, "How much bandwidth is required for collaborative planning?" The amount of bandwidth available to a ship will limit the collaboration tool that can be used and the number of dispersed planners that can be involved in a session - the usual trade off between resources and capabilities.

An examination of the average message delays measured for the various parameter combinations indicate that two or three nodes can successfully conduct a wider range of collaboration session types at 128 kbps when Multicast delivery is implemented. A whiteboard session with accompanying audio and video among two or three nodes is untenable at 128 kbps with Unicast implemented. A bandwidth of 256 kbps enables up to six nodes to conduct a whiteboard with audio session. An even higher bandwidth of 384 kbps provides the ability of six nodes to collaborate via whiteboard with video and audio and for nine nodes to get together in a whiteboard and audio session.

This chapter will present the results and interpretations of the Baseline, Focused and Special Runs. Appendix F contains the Extend model results.

B. GRAPH FORMATS

Two basic graph formats are used to present the results of the model runs – a Baseline graph and a Parameter graph. All the graphs are presented at the end of this Chapter.

1. Baseline Graph

This graph compares the average message delays of text chat, audio, video, and whiteboard messages among the nodes in a three node and nine node scenario, across collaboration session type. An example is shown in Figure 5-1. The title of the graph indicates the network delivery method and the bandwidth used, such as Unicast and 128 kbps. The X-axis lists the collaboration session types. The Y-axis lists the average delay in seconds for a message to travel between two nodes. The plot lines with solid marks represent text chat delays or audio and video delays combined. The plot lines with open marks represent whiteboard delays. An example of an observation from Figure 5-1 is that the three node scenario is the only node scenario with an average delay less than ½ second for the whiteboard and audio (14.4 kbps) session. Refer to Appendix F for actual delay measures.

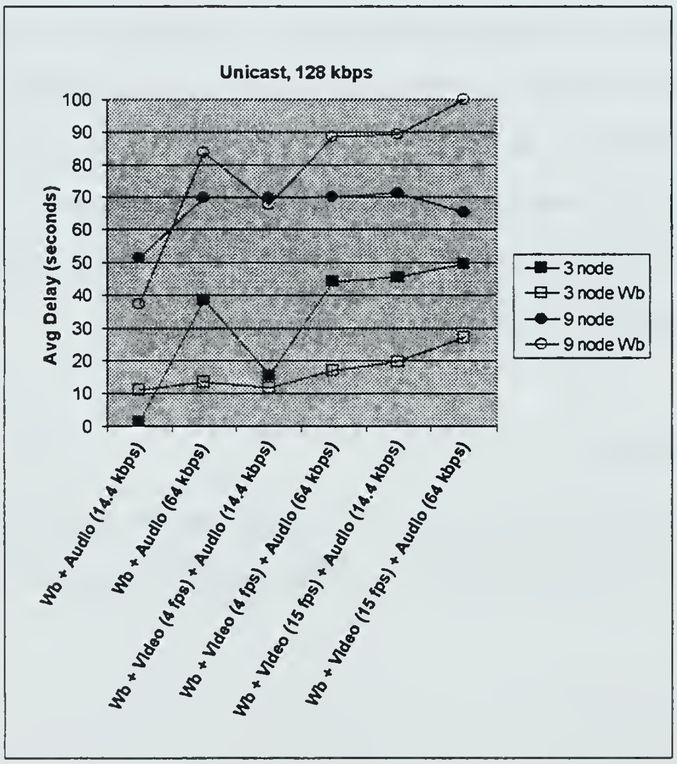


Figure 5-1. Baseline Graph

2. Parameter Graph

The purpose of this graph is to examine the average delays for message deliveries for a specific model parameter across the remaining three model parameters and identify trends or rates of change in performance. Figure 5-2 is an example of this graph. The title indicates the parameter being examined, such as the number of nodes. The X-axis lists the three other parameters – bandwidth, delivery method, and session type. The Y-axis lists the average delay in seconds for a message to travel between two nodes. The plot lines are the same as those in the baseline graphs. An example of an observation is that as the bandwidth increased, the average delays for whiteboard decreased more significantly than did the delays for video/audio.

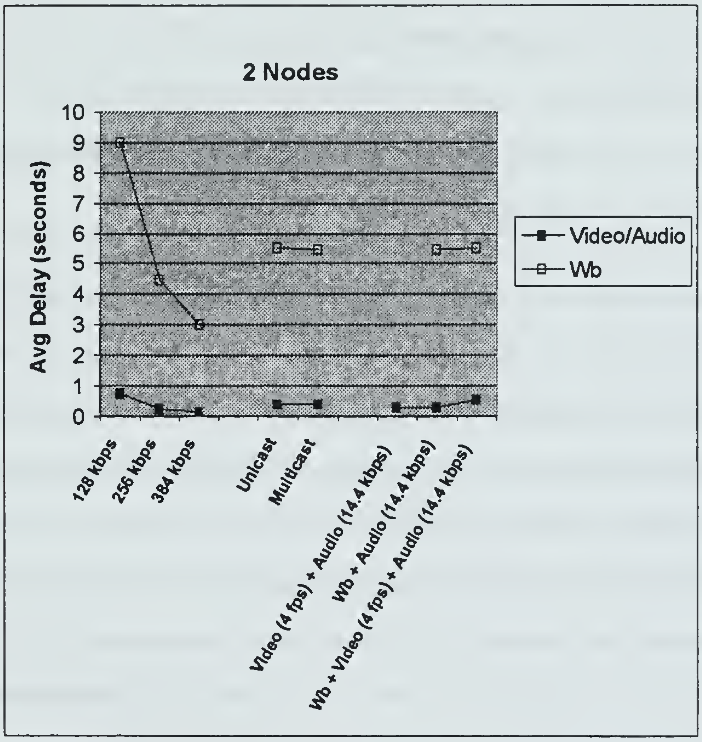


Figure 5-2. Parameter Graph.

C. BASELINE RUNS

Twelve baseline graphs which compare average delays across all combinations of bandwidth and network delivery methods are presented in Figures 5-3, 5-4, 5-5, and 5-6.

As mentioned previously in Chapter V, the nine node runs using 128 kbps and Unicast delivery were so bandwidth limited in the whiteboard session types that several nodes did not receive audio, video or whiteboard messages. All average delays at or above 70 seconds in Figure 5-3c reflect this occurrence.

Interpretations from Figures 5-3, 5-4, 5-5 and 5-6:

- Average delays are reduced as bandwidth is increased from 128 kbps to 384 kbps.

- Multicast delivery reduces the amount of delay. This is more noticeable in the nine node runs. Multicast enables a node to send out one copy of a message instead of tying up all the bandwidth to send out eight copies. It is also faster to send out one message vice eight, so the time saved sending messages can be used to receive messages.

- In Figure 5-3c, the plot line for "9 node" shows a slight decrease in average delays for the most stressing collaboration session combination: whiteboard with high frame rate video and high rate audio. Since only one node is sending out whiteboard pictures to all the other nodes this particular node basically became stalled at 128 kbps trying to send out the pictures. The other nodes did not have their bandwidth tied up receiving a whiteboard picture, so they were receiving and sending video and audio messages with less delays. In other words, the collaboration went on despite the problems encountered by one node.

- Figures 5-3c, 5-4c, 5-5c, and 5-6c show a "dip" in the average delay for the session type "Whiteboard with video at 4 fps and audio at 14.4 kbps rate." The messages for this session type requires 34, 676 bits per second, less than most of the other whiteboard session types listed in Table 5-1. The messages

in that session type can be sent out faster and received faster which results in lower delays. The whiteboard picture was held at a constant size of 572,810 bits across all whiteboard session types.

Collaboration Session Type	Total Audio/Video Bits
Wb + Audio (14.4 kbps)	14,400
Wb + Audio (64 kbps)	64,000
Wb + Video (4 fps) + Audio (14.4 kbps)	34,676
Wb + Video (4 fps) + Audio (64 kbps)	84,276
Wb + Video (15 fps) + Audio (14.4 kbps)	90,435
Wb+ Video (15 fps) + Audio (64 kbps)	140,035

Table 5-1. Collaboration Session Bit Totals.

- In addition to text chat and audio conferencing at 14.4 kbps, three other collaboration session types show potential for being viable combinations for a three node scenario. The sessions are: video (4 fps) with audio (14.4 kbps), whiteboard with audio (14.4 kbps) and whiteboard with video (4 fps) and audio (14.4 kbps). These sessions had average delays near or below the ½ second measure of effectiveness. These session types also appeared to be viable for nine node scenarios at a higher bandwidth of 384 kbps. These three session types were selected for additional runs with parameter settings of 2 and 6 nodes, and 256 kbps.

D. FOCUSED RUNS

Several graph sets are presented in this section to enable comparisons across the parameter values used in the model. Comparisons were conducted by number of nodes, bandwidth, session type, and delivery mode.

1. Number of Nodes Comparison.

Six graphs are presented in Figures 5-7 and 5-8, showing Unicast delivery and Multicast delivery. Three bandwidths are represented: 128 kbps, 256 kbps, and 384 kbps and four node sizes: 2, 3, 6, and 9.

Interpretations of Figures 5-7 and 5-8:

- A bandwidth of 384 kbps with Multicast delivery enables two to nine nodes to successfully engage in all three collaboration session types.
- In a low bandwidth environment, whiteboard with audio at 14.4 kbps or video at 4 fps with audio at 14.4 kbps can be used for sessions with two or three nodes.
- Whiteboard delay times are more constant across all bandwidths in Multicast delivery mode than in Unicast mode. The sending node sends one copy of the whiteboard picture in Multicast mode and the network is responsible for delivery to the other nodes. In many cases the delivery will appear to be "simultaneous" at all nodes, with small delays occurring that are very close in duration. Under Unicast mode, the sending node is limited by its bandwidth and is generally reduced to sending the pictures to the other nodes in series, so the last node on the distribution list will experience longer delays than the first node on the list.
- In a two node scenario, no significant difference in message delays was shown between Unicast and Multicast delivery methods. In each method, a node is only sending one copy of a message. There are no advantages gained by employing Multicast delivery in a point to point communications scenario.

2. Bandwidth Comparison

Three graphs are presented in Figure 5-9 which show, as expected, that a higher bandwidth reduces delays and enables the use of collaboration tools among a larger number of participants.

3. Session Type Comparison

Interpretations for the graphs of three collaboration session types in Figure 5-10, are as follows:

- Multicast delivery significantly reduced the amount of delay in the largest session (in terms of bit size): nine nodes using whiteboard with video at 4 fps and audio at 14.4 kbps, but it was not enough to get the delays below the acceptable level of ½ second. In general, Multicast delivery reduces the bandwidth needed for one transmission by a node intended to reach many destinations. But Multicast delivery does not reduce the bandwidth required at the node to accept many streams of audio and video from other collaborating nodes. The limit on the number of session participants is constrained by the bandwidth at a node.

- Whiteboard delays were greater than audio and video delays in Figure 5-10b and less than audio and video delays in Figure 5-10c. The whiteboard picture consisting of 572,810 bits, was large, even when compared to the maximum of eight audio messages that one node sent out (115,200 bits) and received in (115,200 bits) for a total of 230,400 bits in the nine node scenario. All these bits were competing for bandwidth with the whiteboard at the node so the whiteboard took slighter longer to receive than 115,200 bits. However, in Figure 5-10c, the maximum combination of eight audio and video streams almost doubled to 277,408 bits and, the whiteboard was now competing with incoming and outgoing streams at the node totaling 554,816 bits. The

whiteboard delay did increase but did not double as did the delays for the audio and video messages.

4. Delivery Method Comparison

Figure 5-11 presents the two delivery methods of Unicast and Multicast. As expected, there were lower delays overall when Multicast delivery was implemented.

E. SPECIAL RUNS

Two special runs were conducted: one to simulate a point-to-point Line of Sight scenario that is common between two ships and another run to compare two locations of a multicast router.

1. Point-to-Point Communications

The results shown in Figure 5-12 are similar to those of the two node scenario results presented earlier.

- Multicast Delivery does not reduce delays and does not offer any improvement over Unicast delivery.
- A bandwidth of 128 kbps is still slightly limiting in conducting collaboration sessions within the ½ second acceptable delay. In general, a bandwidth of 256 kbps enables all three types of collaboration sessions to occur.
- Whiteboard delivery delays are greatly reduced when bandwidth is increased, as expected.

2. Multicast Router Location

Delays were added to the three node scenario to simulate processing at the router and propagation times up to and down from a geostationary satellite. The satellite-based multicast router generated the only viable collaboration sessions - whiteboard with 14.4 kbps audio at 256 kbps and 384 kbps bandwidths, that were within the ½ second acceptable delay. No sessions at 128 kbps via the satellite-based router were viable.. The additional round-trip required for messages to travel to the shore-based multicast router increased delays across all session types and bandwidths – no sessions were within acceptable delay range.

F. SUMMARY

Table 5-2 provides a summary of the main results of the model runs. The columns list combinations of Delivery method with bandwidth sizes and the rows list the number of nodes. In each intersection of row and column, there are three letters which represent the collaboration session types. The first letter position from the left, represents the video at 4 fps with audio at 14.4 kbps session type, the second letter position, indicates whiteboard with audio at 14.4 kbps, and the third letter is the whiteboard with video at 4 fps and audio at 14.4 kbps. The use of the letter "Y" indicates that the collaboration session for the combination of delivery method and bandwidth for a particular number of nodes executed with messages arriving within the ½ second timeframe for an acceptable session. An entry of "N" indicates that the collaboration session type for the particular column/row combination did not meet the ½ second criteria for message arrivals. As an example, the intersection of Unicast, 128 kbps with 3 nodes is "NNN" which indicates that message arrivals for all three session types were not below the ½ second criteria.

	Unicast, 128 kbps	Unicast, 256 kbps	Unicast, 384 kbps	Multicast, 128 kbps	Multicast, 256 kbps	Multicast, 384 kbps
2 nodes	Y N N	Y Y Y	Y Y Y	Y N N	Y Y Y	Y Y Y
3 nodes	N N N	Y Y N	Y Y Y	N N N	Y Y Y	Y Y Y
6 nodes	N N N	N N N	N N N	N N N	Y Y N	Y Y Y
9 nodes	N N N	N N N	N N N	N N N	N Y N	N Y N
1st Letter = video (4 fps) + audio (14.4 kbps) 2nd Letter = whiteboard + audio (14.4 kbps) 3rd Letter = whiteboard + video (4 fps) + audio (14.4 kbps)						

Table 5-2. Summary of Results.

The results presented in Table 5-2 show that at 128 kbps, only two nodes can have a video and audio collaboration session. At 256 kbps, two nodes can perform all three session types. At 256 kbps bandwidth, the advantages of Multicast delivery over Unicast also becomes apparent as more nodes can execute more session types. Three nodes can execute an additional session type under Multicast than could be executed under Unicast. Six nodes can execute two collaboration sessions under Multicast that could not be executed under a Unicast with 256 kbps combination.

Multicast with 384 kbps, is the combination with the most options as the two, three, and six node scenarios could execute all three session types. The nine node scenario could execute the whiteboard with audio at 14.4 kbps, and it was very close for the other two session types as both averages were just over the 0.5 second threshold: 0.5135 second delay for the video (4fps) and audio (14.4 kbps) session and 0.5565 second for the whiteboard with video (4 fps) and audio (14.4 kbps).

A high-level view of a network was built and simulated in an effort to gain insight into the use of collaboration tools and using only four general parameters, results were obtained that seemed intuitively obvious. The level of detail inserted into the models is only limited by the expertise of the model builder. A more detailed look at several aspects of collaborative planning at sea and between ship and shore can certainly be built and executed within a reasonable timeframe.

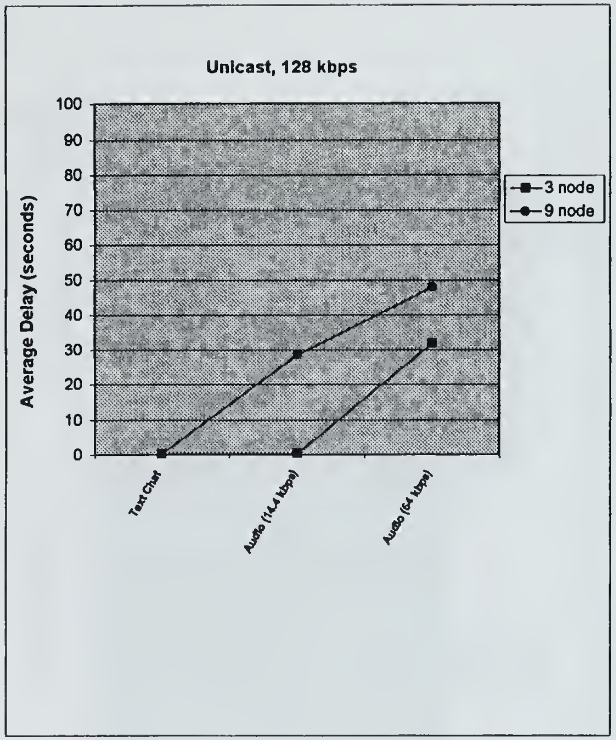


Figure 5-3 a.

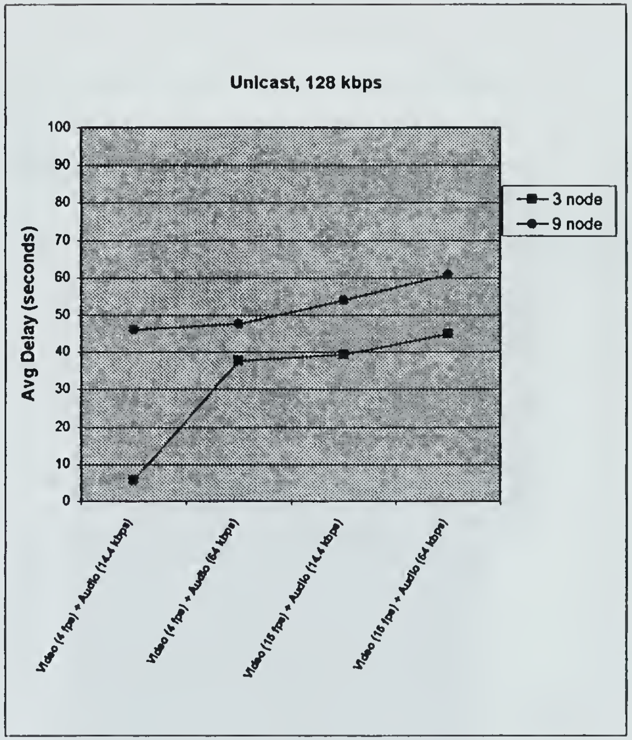


Figure 5-3 b.

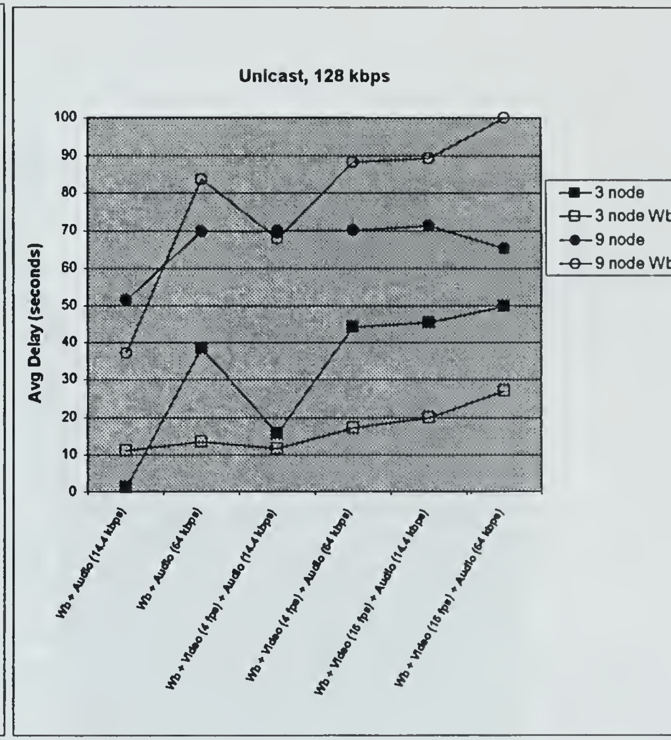


Figure 5-3 c.

Figure 5-3. Unicast with 128 kbps.

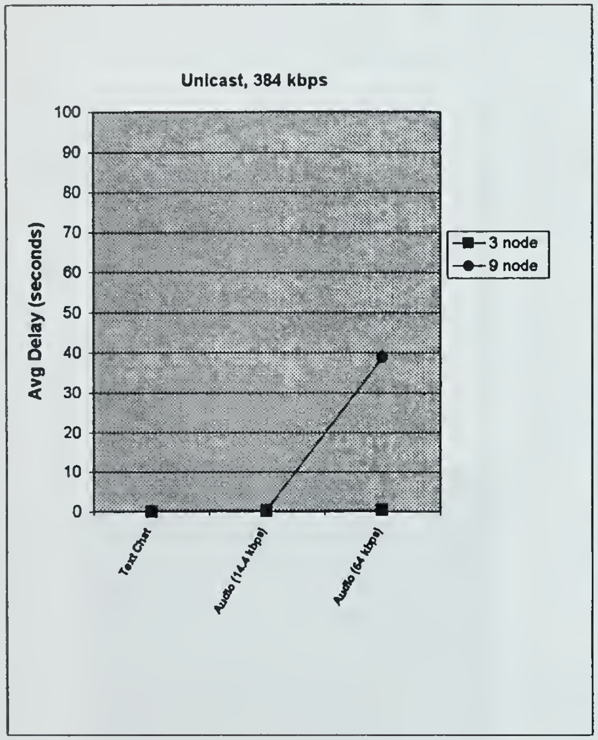


Figure 5-4 a.

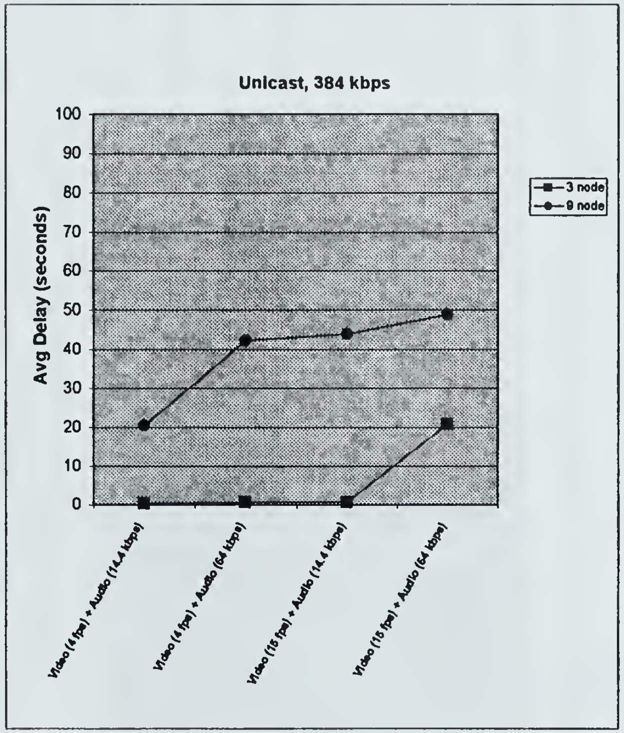


Figure 5-4 b.

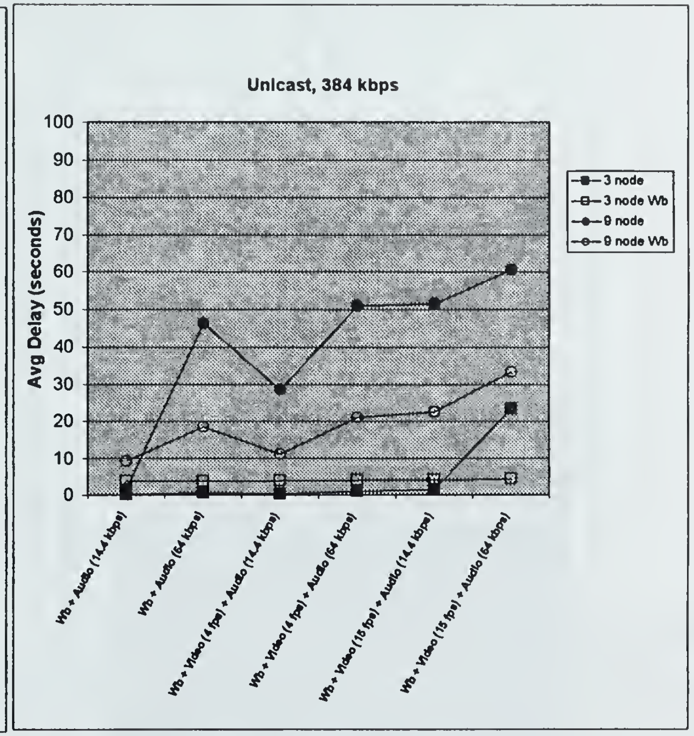


Figure 5-4 c.

Figure 5-4. Unicast with 384 kbps.

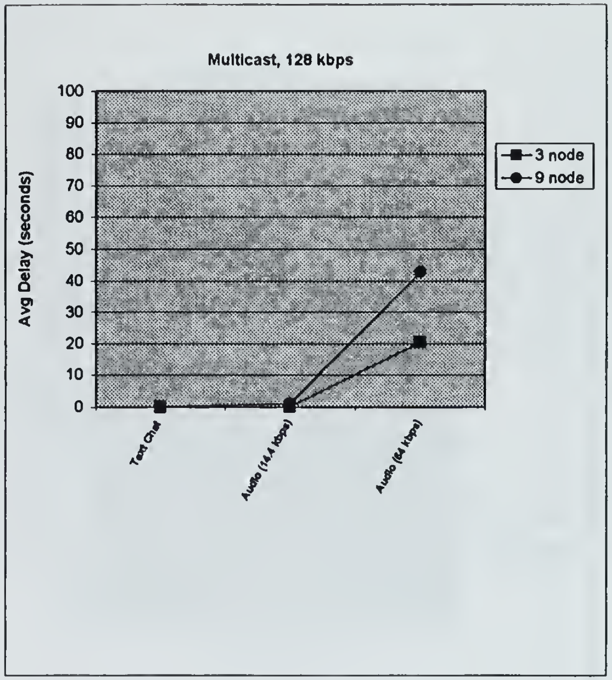


Figure 5-5 a.

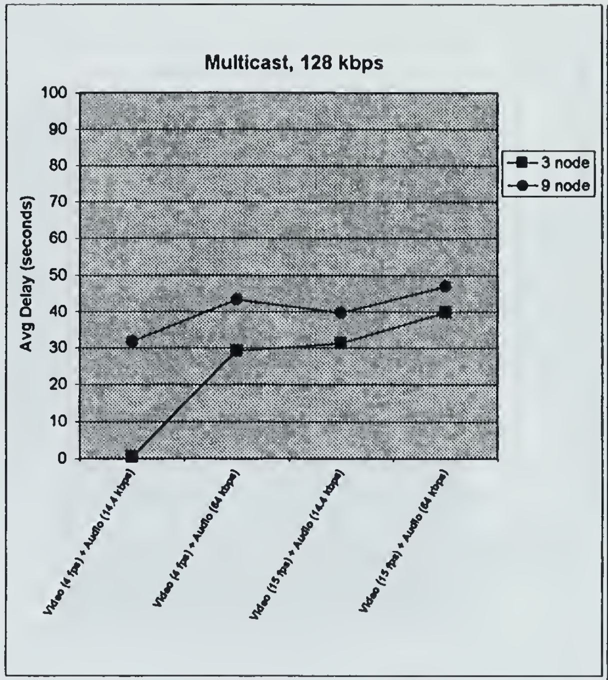


Figure 5-5 b.

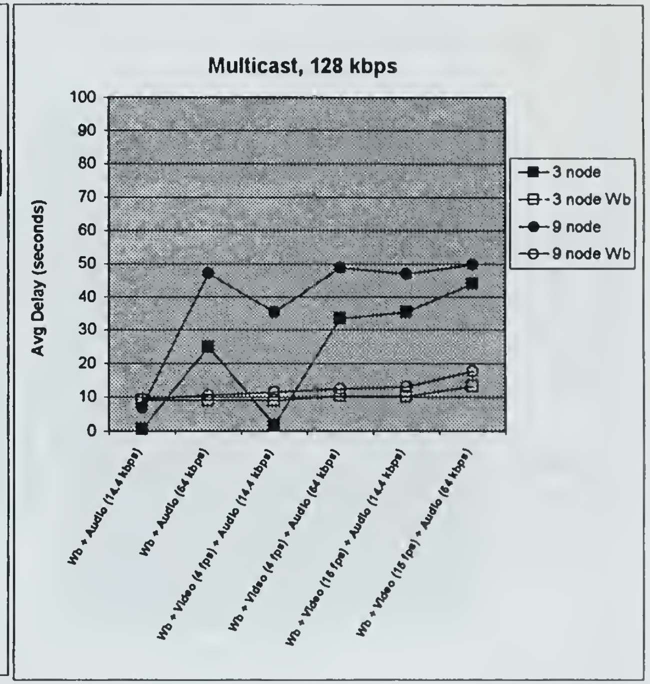


Figure 5-5 c.

Figure 5-5. Multicast with 128 kbps.

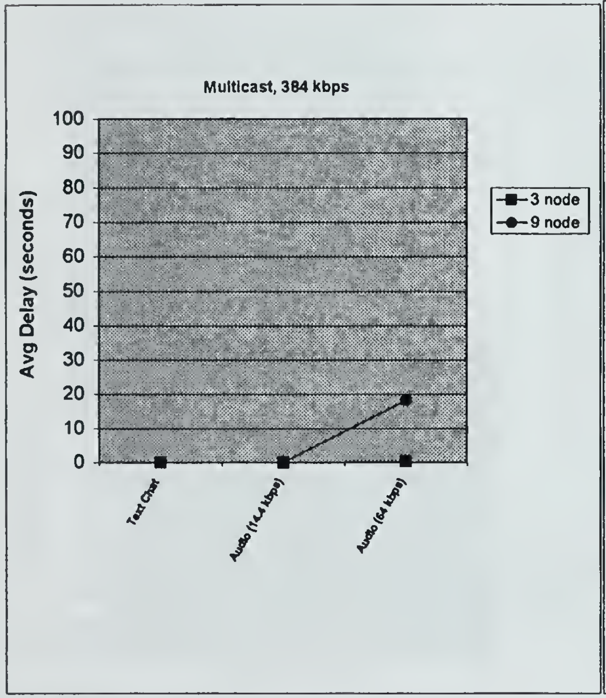


Figure 5-6 a.

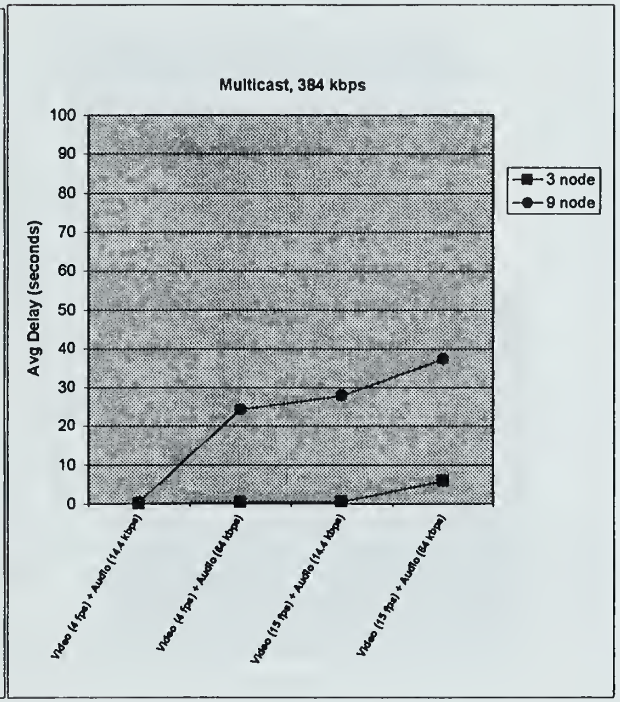


Figure 5-6 b.

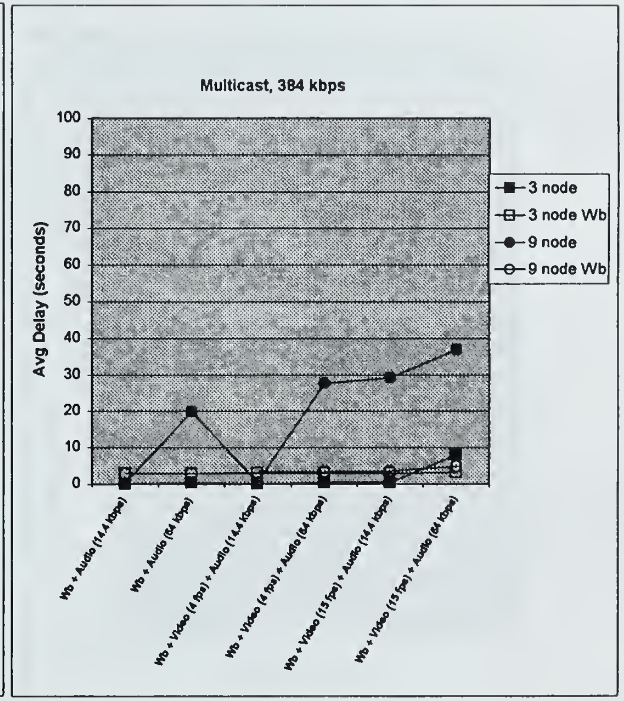


Figure 5-6 c.

Figure 5-6. Multicast with 384 kbps.

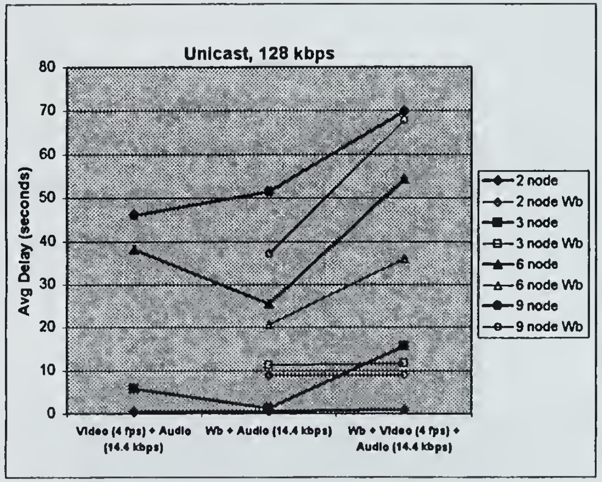
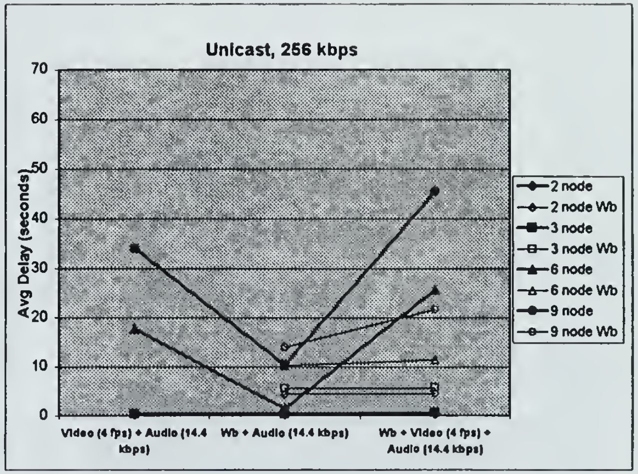


Figure 5-7 a.



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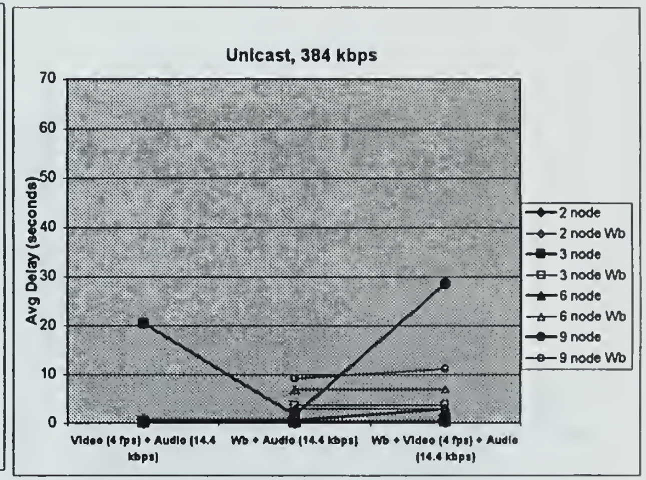


Figure 5-7 c.

Figure 5-7. Number of Nodes (Unicast).

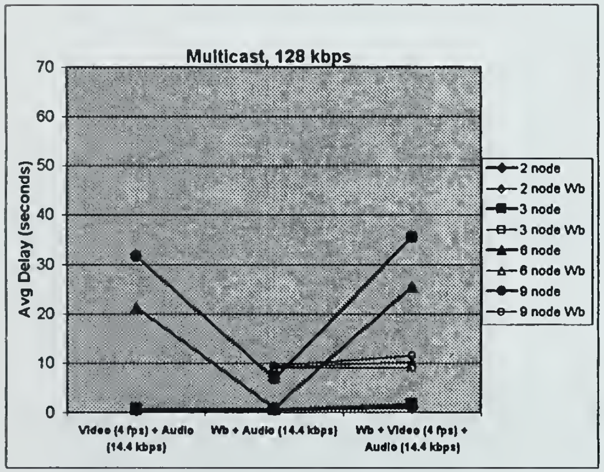


Figure 5-8 a.

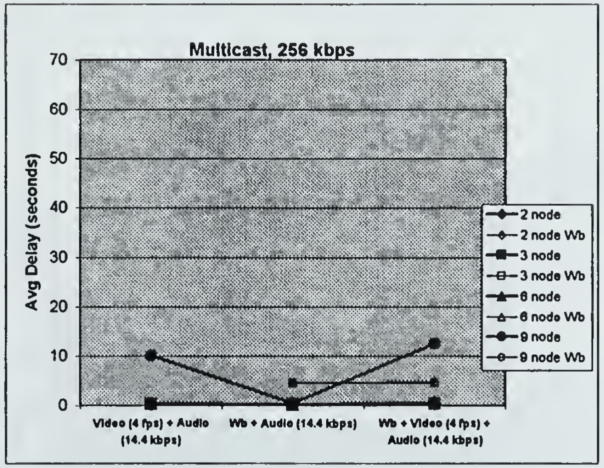


Figure 5-8 b.

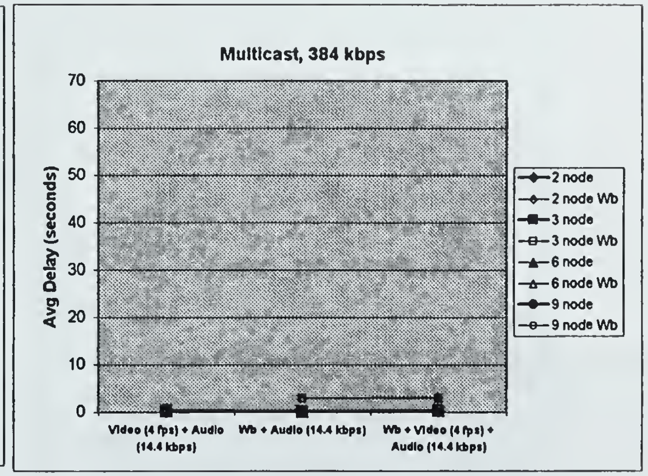


Figure 5-8. Number of Nodes (Multicast).

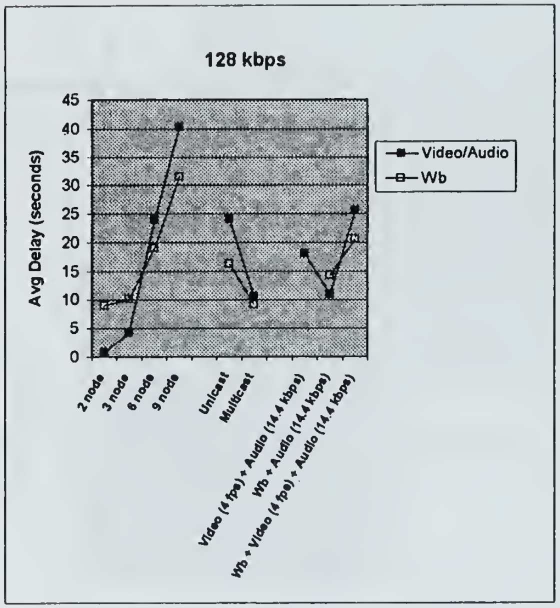


Figure 5-9 a.

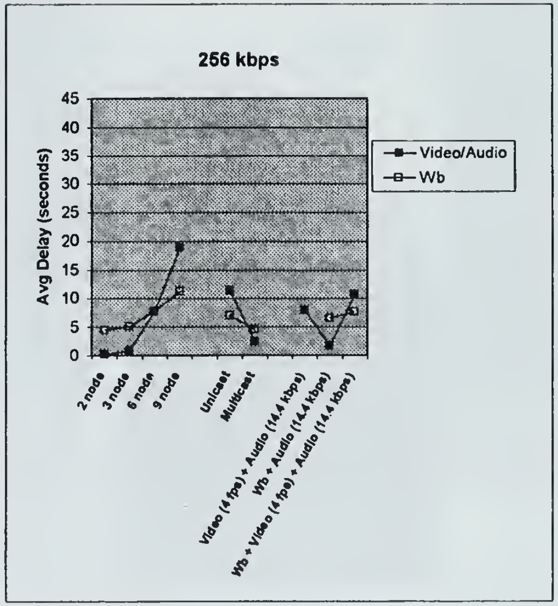


Figure 5-9 b.

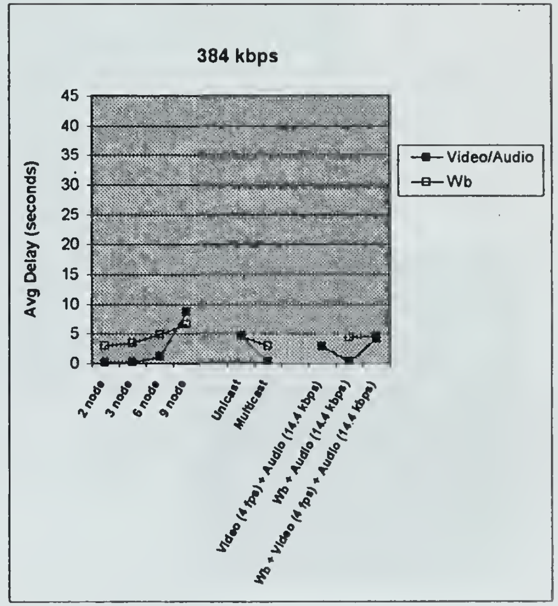


Figure 5-9 c.

Figure 5-9. Bandwidth Comparisons.

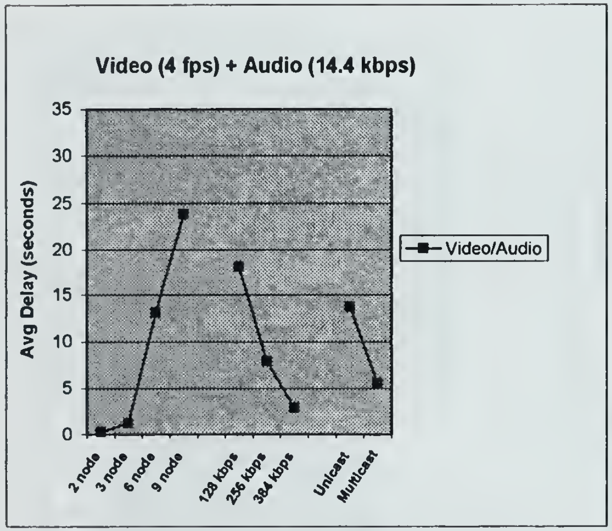


Figure 5-10 a.

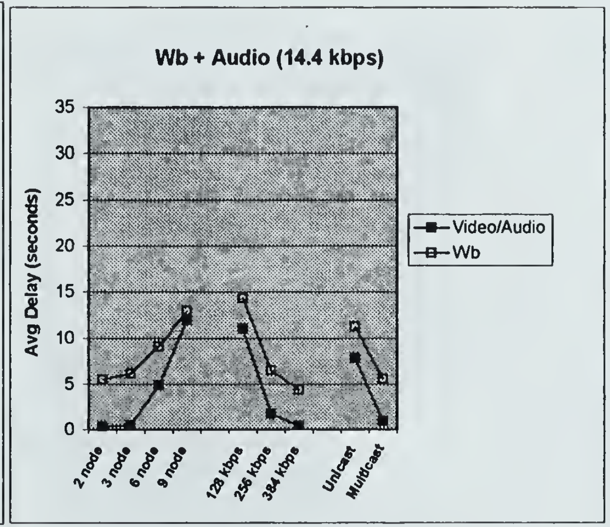


Figure 5-10 b.

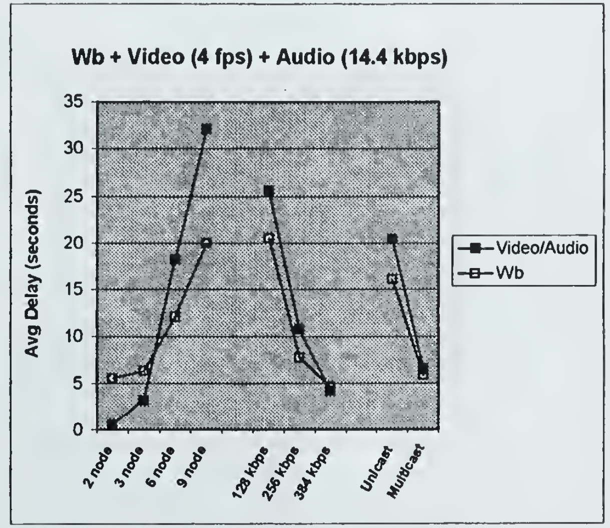


Figure 5-10 c.

Figure 5-10. Session Comparision.

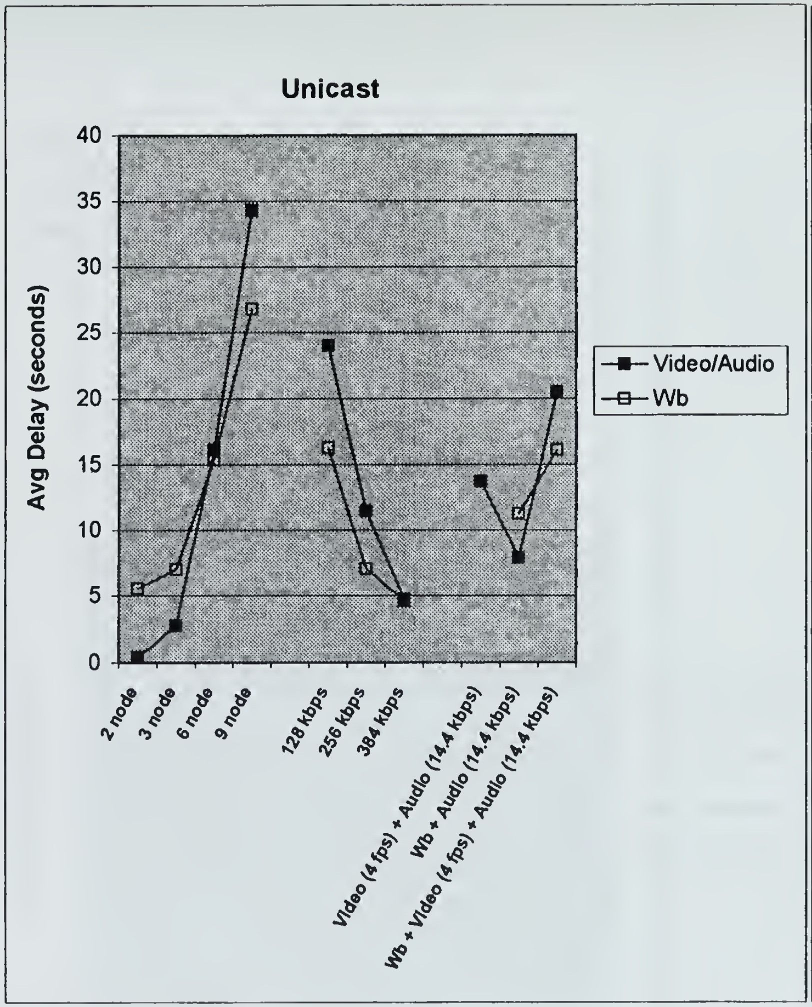


Figure 5-11 a.

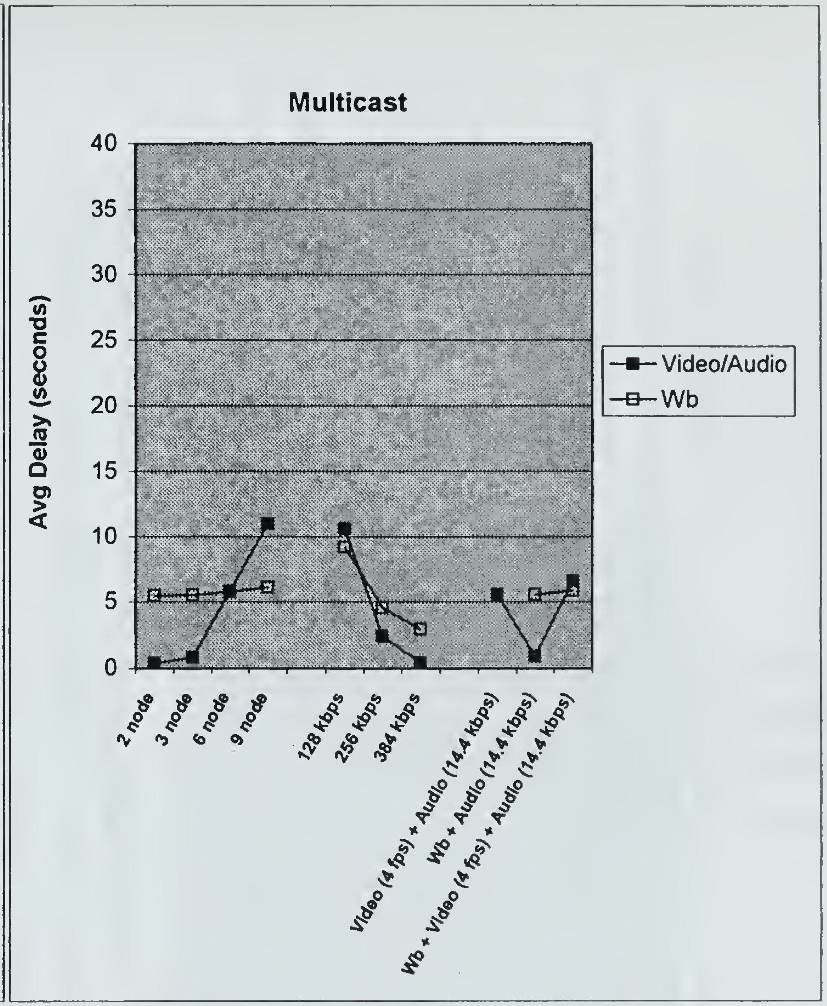


Figure 5-11 b.

Figure 5-11. Delivery Comparison.

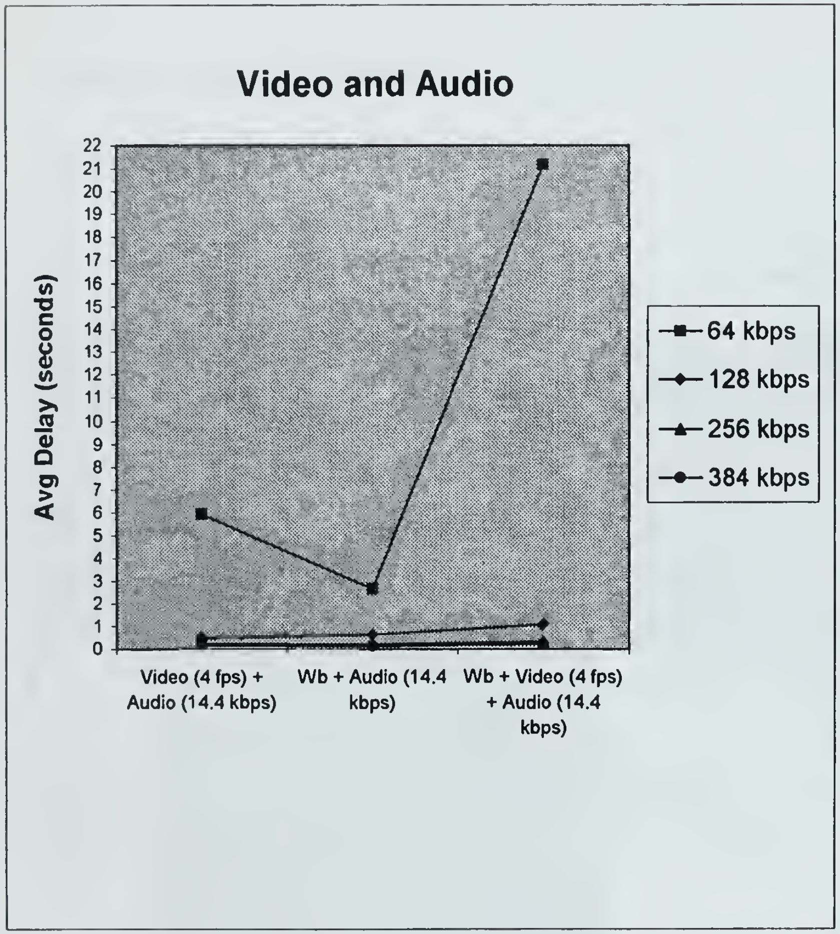


Figure 5-12 a.

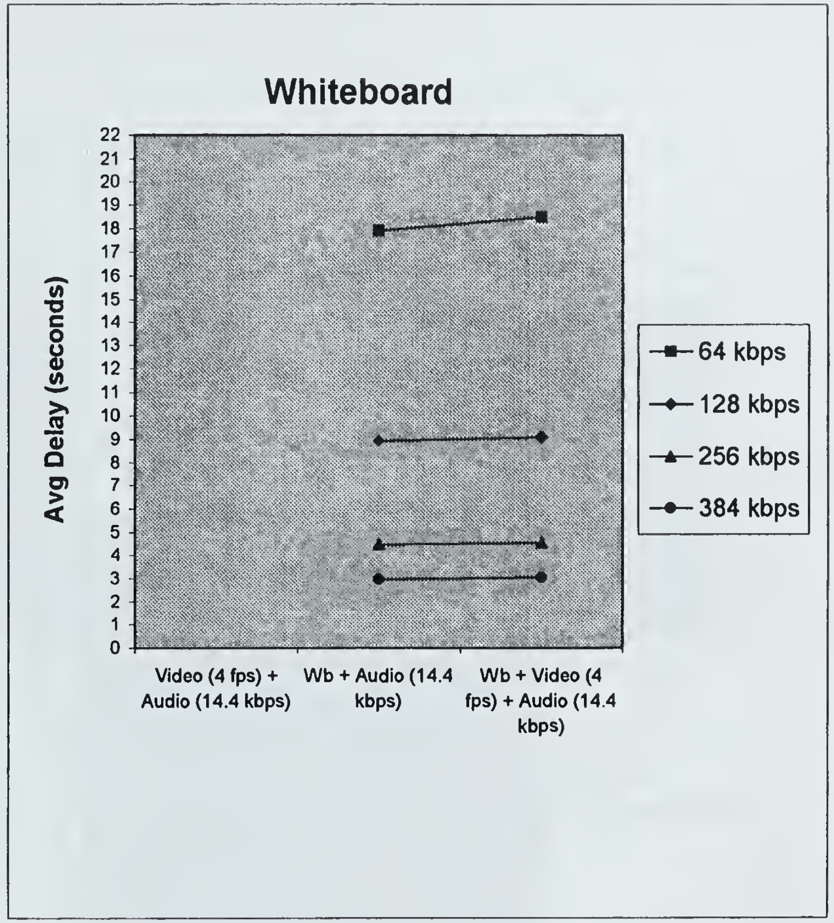


Figure 5-12 b.

Figure 5-12. Point-to-Point.

VI. CONCLUSIONS

How much bandwidth does an amphibious ship need in order to perform collaborative planning? The goal of this thesis was to provide some insight into this question through the use of a high-level simulation model built using a commercial off-the-shelf product called Extend. Over 170 model runs were executed with various combinations of the three collaboration tool types, the amount of bandwidth, the number of planners involved in a planning session, and the type of network delivery method used. The results of these runs are presented from three different aspects, by required collaboration capabilities, by bandwidth, or by the number of other planners that can be involved, as follows:

- Minimum collaboration capabilty required by the ship. If, at a minimum, a ship must be able to conduct a video and audio session with one other ship, than at least 128 kbps must be available to each ship. To conduct a whiteboard with audio session, at least 256 kbps must be available. Whiteboard with video and audio requires 384 kbps.

- Bandwidth is limited. If a ship only has 128 kbps available, then the ship will only be able to conduct a video and audio session with one other ship. At 256 kbps, a ship can collaborate via a video and audio session or a whiteboard with audio session with up to two other sites. At 384 kbps, using multicast delivery, a ship will be able to engage up to eight other sites in a whiteboard with audio session.

- Number of planners required in a collaboration session. To collaborate with one other planner a ship requires at least 128 kbps and a session with two other planners, at least 256 kbps. To collaborate with five to eight other planners, at least 384 kbps must be available at the ship and multicast network delivery must be used to ease the bandwidth congestion at the ship.

To ensure flexibility and adaptability in any planning situation a ship may be engaged in, an optimum mix might be to provide at least 256 kbps bandwidth and use multicast network delivery, so the ship can access some combination of the three collaboration capabilities provided by the tools, with up to five planning counterparts. Without multicast delivery, at least 384 kbps will be required for three ships to engage in a collaborative planning.

The models in this thesis focused only on the bandwidth availability at the ship level and did not model all aspects of network communications and the delays caused by network congestion, the routing protocols used or limitations imposed by satellite capacities and access allocations. Many future studies are possible which focus on these various delays and assess their impact on the use of collaboration tools.

In amphibious planning, the rapid response planning process is six hours. Additional future studies could examine how the use of collaboration tools might affect planning timelines or the sequence of planning events.

APPENDIX A: DII COE CRITERIA FOR COLLABORATION SOFTWARE

The Defense Information Infrastructure Common Operating Environment Multimedia/Collaborative Services Technical Working Group (DII COE MCSTWG) has been established as part of the DII COE and is tasked to define a common core of required capabilities for collaboration software services. This appendix contains the requirements identified for audio, video, and whiteboard applications.

1. Audio conferencing software shall provide:

- Point to point and multipoint, multi-user conferencing
- Multiple operating modes (e.g., support for interactive conference (people sending and receiving from multiple sites), support for one-way conferences (one site sending, all other sites receiving)
- Ability to add/remove users during a conference
- Support for speaker/microphone control.
- Push to talk
- Audio mute on send and receive, near and far
- Support for private side conferences (whisper mode)
- An adjustable bandwidth control
- Adaptation to lowest common audio denominator for lower bandwidth participants (e.g., automatic protocol negotiation)
- Support down to 2400 baud per second and support up to 8 Khz audio.
- Support for secure audio conference channel
- Ability to save and recall audio conference (e.g., in ADPCM, MPEG formats)
- Gateway to other audio conferencing formats

- Support for GSM, LPC-10 (2.4), CELP, and G.700 series interoperability standards

- Support for full duplex

2. **Video conferencing software shall provide:**

- Point to point and multipoint, multi-user conferencing

- Multiple operating modes (e.g., support for interactive conference (people sending and receiving from multiple sites), support for one-way conferences (one site sending, all other sites receiving)

- Ability to add/remove users during a conference

- An adjustable frame rate

- An adjustable compression ratio

- An adjustable image size

- Adaptation to lowest common audio and video denominator for lower bandwidth participants

- Support for rate governing

- Support for secure video conference channel

- Ability to save and recall video conference (MPEG)

- Frame grab video image and save to file (e.g., JPEG, Postscript, GIF)

- Gateway to other conferencing formats

- Support for H.320 series interoperability standards

3. Whiteboard tools shall provide:

- Support for multiple users annotating simultaneously (including individualized cursors that are visually distinct and identify user)
- Ability to import image formats as whiteboard background, including screen capture (window, entire screen, user defined area), NITF, JPEG, GIF, and Postscript
- Support for 8-bit and 24-bit imports
- Ability to export image background and annotations to JPEG (burned in annotations), NITF (nondestructive annotations), Postscript (burned in annotations), TIFF (burned in annotations), GIF (burned in annotations)
- Gesturing/pointing tool
- Text, line, arrow, rectangle, circle, oval, polygon, free draw annotation tools, multi-color annotations
- Ability to import custom symbols for annotations
- Geopositioning of symbols on imported maps
- Attributed annotations (e.g., user, date, comments) and the ability to store and retrieve meta data with annotations
- Ability to overlay vectors (e.g., VPF, CGM) on raster backgrounds.
- Nondestructive whiteboard annotations
- Ability to add/remove users during session
- Persistence of whiteboards for on-going collaborations (e.g., ability to save and recall state)
- Support for Secure whiteboard sessions
- Support for T.126 series interoperability standards
- Plug-in capability to expand functionality

APPENDIX B: COMPARISON OF COLLABORATIVE PRODUCTS

The Defense Information Infrastructure Common Operating Environment Multimedia/Collaborative Services Technical Working Group (DII COE MCSTWG) with assistance from MITRE, conducted an evaluation of audio, video, and whiteboard commercial off-the-shelf products in 1997. The results are presented in the following matrixes.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1		Paradise Simplicity H.323	LBL VAT	Speak Freely	Habanero Audio	Intel Business Video Conferencing with ProShare Technology	Microsoft NetMeeting	Netscape Conference	On-Live Talker	PGP Phone	PictureTel LiveLAN	Sun ShowMe	TeleVOX Pro	VocalTec ICP	VoxChat	White Pines CU-SeeMe
2	Tool Version	1.0	4.0b2	6.1b	1.0b4	1.0	2.0	4.0.3	1.1	1.0b2	3.0	2.01	2.5	2.1	1.0	3.0
3	Solaris 2.5.1	Yes (Fall 97)	Yes	Yes	Yes	No	No	Yes	No	No	No	Yes	No	No	No	No
4	HP-UX	Yes (Fall 97)	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No
5	NT	Yes (Fall 97)	Win95, NT 4.0	Win95, NT 4.0	No, planned	Win95, NT 4.0 (Planned)	NT 4.0	NT 3.5.1, NT 4.0	Win95, NT 4.0	Win95, NT 4.0	Win95, NT 4.0 (End of 97)	No	Win95, NT 4.0	Win95, NT 4.0	Win95, NT 4.0	Win95, NT 4.0
8	IP-based	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Multiuser conferencing (>2 users)	Yes, via Multicast or MCU (planned)	Yes, via Multicast	Yes, via Peer to Peer or Multicast	Yes, via Conference Server	Yes, via MCU (planned)	Yes, via MCU (planned)	Yes, via MCU (planned)	Yes, via MCU	No	Yes, via MCU (planned)	Yes, via Peer to Peer or Multicast	Yes, via Peer to Peer	Yes, via MCU	Yes, via MCU	Yes, via Reflector or Multicast
8	Interactive conferences [Full duplex, half duplex]	Full, Half	Full, Half	Full, Half	Full, Half	Full, Half	Full, Half	Full, Half	Full, Half	Full, Half	Full	Full, Half	Full, Half	Full, Half	Full, Half	Full, Half
9	1-way broadcast conferences	Yes, via Multicast or MCU (planned)	Yes, via Multicast	Yes, via Peer to Peer or Multicast	Yes, via Conference Server	Yes, via MCU (planned)	No	No	Yes, via MCU	No	Yes, via MCU (planned)	Yes, via Peer to Peer and Multicast	Yes, via Peer to Peer	Yes, via MCU	Yes, via MCU	Yes, via Reflector and Multicast
10	Push to talk	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
11	Manual codec selection during conference for bandwidth control	No	Yes	Yes	No	No	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes
12	Dynamic addition/removal of users during conference	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	Yes, can remove oneself and "new" users	No, removal of self only	No, removal of self only	No, removal of self only
13	Conference participation control (private, no eavesdropping) (Not security)	No for Multicast, Yes for MCU (planned)	DES encryption	IDEA, DES, key file encryption on packets	Yes	Yes	Yes	Yes	No-must be done through web page interface	triple-DES, CAST, Blowfish encryption	Yes	Yes for Peer to Peer, No for Multicast	Yes	Yes	Yes	Yes for Reflector, No for Multicast
14	G.711	Yes (64 Kbps)	No	No	No	Yes	Yes (32 Kbps)	Yes	No	No	Yes (64 Kbps)	No	Yes	No	No	No
15	G.723.1	No	No	No	No	Yes	Yes (5 Kbps)	No	No-planned	No	No	No	No	No	No	No
16	G.728	Yes (16 Kbps) using H/W	No	No	No	Yes	No	No	No	No	Yes (16 Kbps)	No	No	No	No	No
17	GSM	GSM 8.10 (13.3 Kbps)	GSM (17 Kbps)	GSM (17 Kbps)	No	No	No	No	No	GSM, GSM-lite	No	No	No	Yes	Yes	No
18	LPC-10 (2.4)	No (planned)	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
19	CELP	No	No	No	No	No	Lernout & Hauspie CELP 4 (5 Kbps)	No	No	No	No	No	No	No	No	No
20	Other CODECs supported	ADPCM (32 Kbps)	PCM (78, 71, 68 Kbps), Intel DVI ADPCM (48, 39, 38 Kbps), LPC4 (9Kbps)	ADPCM (40 Kpbs), LPC (6.5 Kbps), "simple compression " (40 Kbps)	No (planned)	None	Lernout & Hauspie SBC 18 (18 Kbps), SBC 8k (8 Kbps), SBC 12 (12 Kbps), Microsoft ADPCM 8,000 H (32 Kbps)	Elemedia SX8300P (8.3 Kbps), Voxware RT29HQ (2.9 Kbps), Voxware RT24 (2.4 Kbps)	OnLive proprietary	ADPCM	G.722 (64 Kbps), PT724 (24 Kbps)	None	Voxware RT29HQ (2.9 Kbps), Voxware RT24 (2.4 Kbps)	VocalTec proprietary	Voxware RT29HQ (2.9 Kbps)	Intel DV1 (32kbps), Delta-Mod (16kbps), DigiTalk (8.5kbps), Voxware (2.4kbps)
21	Max # users in conference	32 senders	Bandwidth limited	Bandwidth limited	Unknown	MCU-Dependent	MCU-Dependent	MCU-Dependent	100	2	MCU-Dependent	Bandwidth limited	5	150	100	Bandwidth limited
22	Mic volume control	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes
23	Mic mute on send	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1		Paradise Simplicity H.323	LBL VAT	Speak Freely	Habanero Audio	Intel Business Video Conferencing with ProShare Technology	Microsoft NetMeeting	Netscape Conference	On-Live Talker	PGP Phone	PictureTel LiveLAN	Sun ShowMe	TeleVOX Pro	VocalTec ICP	VoxChat	White Pines CU-SeeMe
24	Output volume control	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
25	Audio mute on receive end	Yes	Yes	No	Yes	Set volume to zero	Yes	Yes	Yes	No	Set volume to zero	Yes	Yes	Yes	No	Yes
26	Dynamic bandwidth allocation	No	No	No	No	Yes	No	No	Yes, via Server	No	No	No	No	No	No	No
27	Lowest supported connection speed	28.8 Kbps	17 Kbps	14.4 Kkbps	28.8 Kbps	200 Kbps (video must be on)	14.4 Kbps	14.4 Kbps	15Kbps/user	14.4 Kbps	64 Kbps per user	84 Kbps per user	14.4 Kbps		14.4 Kbps	28.8 Kbps
28	Hands free talk mode	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
29	Save audio conference	No	No	No	No	Yes	No	No	No	No	No (Planned, Video Warehouse, 2nd Half of 97)	No	No	No	No	No
30	Supports simultaneous side audio conversations	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes, with single person in confernece
31	Notes		Can mute individual users	Transmit pre-recorded audio for broadcast; Supports voice mail	Can mute individual users	Waiting on 3rd party MCU for mutipoint audio/video		Supports click to turn talk on/off	Can mute individual users		Has Automatic Gain Control	Sun has an H.323 product in the works		Moderator decides who can speak	Host can silence participants globally In conference; Automatic Gain Control, Ignore User feature	
32	Known Issues				Audio is a demo only	Intel video capture/audio board required					Audio/Video codec board required					

	A	B	C	D	E	F	G	H	I	J
1		Paradise Simplicity H.323	LBL VIC	Intel Business Video Conferencing with ProShare Technology	Microsoft NetMeeting	Netscape Conference	PictureTel LiveLAN	Sun ShowMe	White Pines CUSeeMe	Xerox PARC NV
2	Tool Version	1.0	2.8	1.0	2.0	4.0.3	3.0	2.01	3.0	3.3beta
3	Solaris 2.5.1	Yes (Fall 97)	Yes	No	No	No Video	No	Yes	No	Yes
4	HP-UX	Yes (Fall 97)	9.0.5	No	No	No Video	No	No	No	Yes
5	NT	Yes (Fall 97)	Win95, NT 4.0	Win95, NT4.0 (Planned)	NT 4.0	No Video	Win95, NT 4.0 (End of 97)	No	Win95, NT 4.0	No
6	IP-based	Yes	Yes	Yes	Yes	No Video	Yes	Yes	Yes	Yes
7	Multiuser conferencing (>2 users)	Yes, via Multicast or MCU (Fall 97)	Yes, via Multicast	Yes, via MCU (planned)	Yes, via MCU (planned)	No Video	Yes, via MCU (planned)	Yes, via Peer to Peer or Multicast	Yes, via Reflector or Multicast	Yes, via Multicast
8	1-way broadcast conferences [MCU, Multicast, Peer to Peer]	Multicast first; MCU will be added later	Multicast	No	No	No Video	No, but MCU is planned for 2nd Half of '97	Peer to Peer and Multicast	MCU and/or Multicast (via Reflector)	Multicast
9	Mute sending of video	No	No	Yes	No, but has a pause feature	No Video	No	Yes	No, but has hold feature	No
10	Video transmission control - Receive only - Receive and transmit	Yes	Yes	Yes	Yes	No Video	Yes	Yes	Yes	Yes
11	User bandwidth control - Adjustable frame rate - Adjustable compression ratio - Adjustable image size	Adjustable frame rate; Adjustable compression ratio; Adjustable image size	Adjustable frame rate; adjustable compression by selecting new encoder; adjustable image size	Adjustable frame rate; Adjustable image size	Adjustable video quality (changes a combination of compression and frame rate used); Adjustable image size	No Video	Adjustable frame rate; Adjustable compression ratio; Adjustable image size	Adjustable frame rate; Adjustable image size	Adjustable video quality (changes frame rate used); can select different video codecs; adjustable image size among different predefined sizes	Adjustable compression by selecting new encoder; Adjustable image size
12	Dynamic addition/removal of users during conference	Removal of self	Removal of self	Removal of self	Removal of self	No Video	Removal of self	Removal of self	Removal of self	Removal of self
13	Conference participation control (private, no eavesdropping) (Not security)	Yes	Yes, via DES Encryption	Yes	Yes	No Video	Yes	Yes	Yes - at Reflector	No
14	H.261	Yes, FCIF and QCIF	Yes, FCIF and QCIF	Yes, FCIF and QCIF	Yes, FCIF and QCIF	No Video	Yes, FCIF and QCIF	No	No	No
15	H.263	No	No	Yes	Yes	No Video	No	No	Yes	No
16	Other CODECs supported	M-JPEG	nv; Sun CellB; MJPEG; H.261	None	None described	No Video	None	CellB	WhitePine M-JPEG WhitePine Color Cornell CU-SeeMe Gray	nv, Sun CellB, CUSeeMe
17	Max # users in conference	32	Bandwidth limited	MCU-dependent	MCU-dependent	No Video	MCU-dependent	Bandwidth limited	Bandwidth limited	Bandwidth limited

	A	B	C	D	E	F	G	H	I	J
1		Paradise Simplicity H.323	LBL VIC	Intel Business Video Conferencing with ProShare Technology	Microsoft NetMeeting	Netscape Conference	PictureTel LiveLAN	Sun ShowMe	White Pines CUSeeMe	Xerox PARC NV
18	Dynamic bandwidth control - Adjustable frame rate - Adjustable compression ratio - Adjustable image size	Adjustable frame rate; Adjustable compression ratio	Adjustable frame rate; adjustable compression by selecting new encoder; adjustable image size	LANDesk Conferencing Manager can dynamically limit the number of conferences as well as the bandwidth used in each conference based on overall network consumption. Automatically limiting the bandwidth effectively limits the frame rate at the client.	Adjustable video quality (changes a combination of compression and frame rate used); Adjustable image size	No Video	Adjustable frame rate; Adjustable compression ratio; Adjustable image size	No	Adjustable video quality (changes frame rate used); can select different video codecs; adjustable image size among different predefined sizes	Adjustable compression by selecting new encoder; Adjustable image size
19	Adapt to lowest common denominator	No	No	Yes - auto negotiation (sharper versus smoother)	No	No Video	Yes - auto negotiation	No	No	No
20	Rate governing	Yes	Yes	Yes - 200 Kbps versus 450 Kbps		No Video	Yes	No	Yes	Yes
21	Save video conference	No	No	A video recorder for this product is in development	No	No Video	Hook up VCR now or use LiveWarehouse due to come out this year	No	No	No
22	Frame grab a video image (list file format)	No - operator must use 3rd party snapshot tool, e.g., Sun Image Tool for Unix or Xv for NT	No	Yes - snapshot into *.bmp, *.tif, and *.gif formats	Yes - snapshot to *.bmp	No Video	Yes - snapshot into *.bmp format	Yes - snapshot into Sun Raster format	No	Yes
23	Other			MCU pending	MCU pending	No Video	MCU pending; LiveLAN 3.5 will also support multicast and H.263	Video Mute; also, Sun has an H.323 product in the works		
24	Known Issues			Intel video capture/audio board required		No Video	Audio/Video codec board required			

	A	B	C	D	E	F	G	H	I	J	K	L
1		Paradise Simplicity H.323	DataBeam FarSite	Habanero Whiteboard	Intel Business Video Conferencing with ProShare Technology	LBL WB	Microsoft NetMeeting	Netscape Conference	PictureTel LiveLAN	Sun ShowMe	VocalTec ICP	WhitePines CUSeeMe
2	Tool Version	1.0	3.07	1.0b4	1.0	1.59	2.0	4.0.3	3.0	2.01	2.1	3.0
3	Solaris 2.5.1	Yes (Fall 97)	No	Yes	No	Yes	No	Yes	No	Yes	No	No
4	HP-UX	Yes (Fall 97)	No	Yes	No	Yes	No	Yes	No	No	No	No
5	NT	Yes (Fall 97)	Win95, NT 4.0	Win95, NT4.0	Win95, NT4.0 (Planned)	No	Win95, NT 4.0	Win95, NT 4.0	Win95, NT 4.0 (End of 97)	No	Win95, NT 4.0	Win95, NT4.0
6	IP-based	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Multiuser conferencing (>2 users)	Yes, via Multicast or MCU (Fall 97)	Yes, via Peer to Peer or MCU	Yes, via Conference Server	Yes, via Peer to Peer	Yes, via Multicast	Yes, via Peer to Peer or MCU	No	Yes, via Peer to Peer or MCU	Yes, via Peer to Peer or Multicast	Yes, via MCU	Yes, via Reflector or Multicast
8	Import backdrop formats (8 and 24-bit) - Captured window - Selected screen area - JPEG image - Raster image - NITF image (bring in meta data) - GIF image - Postscript image	Captured Window, Selected Screen Area, JPEG, Raster, NITF 2.0 (but uncompressed and no metadata)	Captured Window, Selected Screen Area, JPEG	JPEG, GIF	Captured Window, Selected Screen Area	Postscript	Captured Window, Selected Screen Area	Captured Window, Selected Screen Area (inside app), GIF, JPEG	Captured Window, Selected Screen Area	Captured Window, Selected Screen Area, Sun Raster	Captured window, Selected screen area, JPEG	Captured Window, Selected Screen Area, JPEG
9	Export backdrop image and burned in annotations - JPEG - TIFF - GIF - Postscript - NITF (annotations not burned in with meta data)	JPEG, TIFF, GIF	TIFF, JPEG	None	None	None	None	JPEG, TIFF	None	JPEG	None	TIFF, JPEG
10	Nondestructive annotations during session	Yes, but can't select or relocate annotations	Yes	Yes	Yes	Yes	Yes	Yes, but can't select or relocate annotations	Yes	Yes, but can't select or relocate annotations	Yes, but can't select or relocate annotations	Yes
11	Annotation tools for text, line, arrow, rectangle, circle, oval, polygon, freedraw	Yes except no arrow, no polygon	Yes except no arrow, no polygon	Yes, no arrow, cirlce, polygon	Yes except no arrow, no polygon	Yes, excpet no circle or polygon	Yes except no arrow, no polygon	Yes except no arrow, no polygon	Yes except no arrow, no polygon	Yes except no arrow (besides a stamp), and no polygon	Yes, including diamond, no polygon	Yes except no arrow, no polygon
12	Conference participation control (private, no eavesdropping) (Not security)	No	Yes		Yes	DES encryption	Yes	Yes	Yes	Yes	Yes	Yes, via Reflector only
13	Gesturing/pointing tool	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes

	A	B	C	D	E	F	G	H	I	J	K	L
1		Paradise Simplicity H.323	DataBeam FarSite	Habanero Whiteboard	Intel Business Video Conferencing with ProShare Technology	LBL WB	Microsoft NetMeeting	Netscape Conference	PictureTel LiveLAN	Sun ShowMe	VocalTec ICP	WhitePines CUSeeMe
14	Dynamic addition/removal of users during session	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	No, removal of self only	Yes	No, removal of self only	No, removal of self only
15	Multiple users (>2) annotating simultaneously	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
16	Persistence of whiteboards for use in future sessions	No - can only save burned-in images	Yes	No	Yes	No	Yes	Yes	Yes	No - can only save burned-in images	Yes	Yes
17	T.126	No, planned	No, planned	No	No, planned	No	No, planned	No	No, planned	No, planned	No	No, planned
18	Other Import backdrop formats (list)	TIFF, BMP, TARGA	Captured Desktop, TIFF, FST, BMP, DIB, PCX, TGA, PCT, EPS, WPG, WMF, DCX	None	WHT	Text	WHT	Captured Desktop, TIFF, BMP	WHT	None	MS Office docs and any OLE server object	Captured Desktop, TIFF, FST, BMP, DIB, PCX, TGA, PCT, EPS, WPG, WMF, DCX
19	Other Export backdrop formats	BMP	FST, BMP, DIB, PCX, TGA, PCT, EPS, WPG, WMF, DCX	No	WHT	No	WHT	BMP	WHT	Sun Raster	CFR	FST, BMP, DIB, PCX, TGA, PCT, EPS, WPG, WMF, DCX
20	Multi-color annotations	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
21	Functionality plug-ins	No	No	No	No	No	No	No	No	No	No	No
22	Import custom symbols for annotations	No	No	No	No	No	No	No	No	No	No	No
23	Overlay vector graphics (VPF, CGM) on raster backgrounds	No	No	No	No	No	No	No	No	No	Yes, if from an OLE server	No
24	symbols on imported maps	No	No	No	No	No	No	No	No	No	No	No
25	Attributed annotations: user, date, comments	No	No	No	No	No	No	No	No	No	No	No
26	Known Issues		16-bit	Whiteboard is a demo only								
27	De-synchronize	No	No	No	Yes	No	Yes	No	Yes	No	No	No
28	Can lock whiteboard contents	No	No	No	Yes	No	Yes	No	Yes	Yes - bottom layer	No	No
29	Highlighter	No	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes
30	Filled rectangle option	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes
31	Filled circle/oval option	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes
32	Eraser	Yes	Select and delete	Select and delete	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Select and delete
33	Zoom capability	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes

	A	B	C	D	E	F	G	H	I	J	K	L
1		Paradise Simplicity H.323	DataBeam FarSite	Habanero Whiteboard	Intel Business Video Conferencing with ProShare Technology	LBL WB	Microsoft NetMeeting	Netscape Conference	PictureTel LiveLAN	Sun ShowMe	VocalTec ICP	WhitePines CUSeeMe
34	Copy and paste annotations	No	Yes - but only from one page to another within the whiteboard, not within a page and not to outside applications	No	Yes - both from within a page and from one page to another within the whiteboard as well as to outside applications	Yes	Yes - both from within a page and from one page to another within the whiteboard as well as to outside applications	Yes - can select annotation region and paste it as a bitmap; Can also paste text/graphics from other applications as bitmaps	Yes - both from within a page and from one page to another within the whiteboard as well as to outside applications	No	No, but can copy and paste OLE objects onto and within whiteboard	Yes - but only from one page to another within the whiteboard; not within a page and not to outside applications
35	Move annotations Print whiteboard	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes
36	contents	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
37	Multi-page	No	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes
38	Conference participants idantified	Yes	Yes	Yes	Yes	Yes	Yes	Only two can participate in a whiteboard session	Yes	Yes	No	Yes
39	Notes	Original Whiteboard Software	Original Whiteboard Software		Uses MS NetMeeting for the Whiteboard		Original Whiteboard Software	Original Whiteboard Software	Uses same core software as MS NetMeeting for the Whiteboard; LiveLAN 3.5 will run under NT4.0 and will use the MS NetMeeting application that comes bundled with NT4.0 for its data conferencing tool	Sun has T.120 product in the works		Uses Databeam's FarSite for the Whiteboard

APPENDIX C: BANDWIDTH REQUIREMENTS MATRIX

The following matrix was put together to consolidate bandwidth requirements for collaborative planning or for collaboration tools encountered by the author during her research. The sources are listed in the first column.

Source	Collaborative Planning		
JWID 97 Lessons Learned Report Sept 97 (DISA)	256 kbps to unit level		
CINCPACFLT IT-21 Brief	384 kbps		
IT-21 (Govt Computer News 28 Jan 98)	128 kbps is IT-21 core capability; 1.5 Mbps for CVs and Amphibs		
Naval Space Command -CC4750 Lecture Notes Fall 97	512 kbps for Command/VTC; 1.544 Mbps for imagery		
Source	**Desktop Video Conferencing**	**Audio Conferencing**	**Whiteboard (wb)**
Bill Abbuhl, MITRE (email 3 Mar 98)	6 displays total 384 kbps		32 kbps per person
Collaboration Across the Coalition Report (MITRE Sept 97)	32 to 128 kbps per person or at least 15 fps		2.4 kbps for annotations
Sun Showme website (www.sun.com)	minimum 14 kbps 160 X 120 at 15 fps = 215 to 430 kbps 320 X 240 at 15 fps = 860 to 1730 kbps	uncompressed, using 8 bits per sample = 64 kbps per person	64 kbps adequate for wb & low frame rate video
Isaacs, E. A. and Tang J.C., "Why do Users Like Video? Studies of Multimedia-Supported Collaboration, December 1992	users can tolerate 5 fps	minimum range for delays is 0.22 to 0.44 seconds	
Lawrence Livermore Berkeley Lab (LLBL): developer of multicast tools (www-nrg.ee.lbl.gov)	25 kbps to 128 kbps	14.4 kbps minimum	
"MBONE Provides Audio and Video Across the Internet", Macedonia, Brutzman, (www.llnl.gov)	128 kbps 1-4 fps is acceptable, 3 fps over Internet		
"Multicasting for Sound and Video" article in Unix Review, Feb 94	128 kbps for 3 - 5 fps	32 kbps ADPCM; 13 kbps GSM; 4 - 8 kbps CELP - all of which require software compression	
Cu-SeeMe application developed by Cornell University (http://gated.cornell.edu)	120 X 160 frame size: 75 kbps (uncompressed), 45 kbps (compressed); 100 kbps if fluid motion	at least 16 kbps	
MS NetMeeting application (Infoworld Jun 97)	3 - 7 fps over 28.8 modem		
CISCO paper "Networked Multimedia Overview" (www.cisco.com)	128 kbps to 1 Mbps	64 kbps	
"A Reliable Multicast Framework for Light-weight Sessions and Application Level Framing", Floyd, Jacobson, Liu, McCanne, and Zhang, Nov 1996			in general, wb uses less bandwidth than the accompanying audio

Bandwidth Requirements.

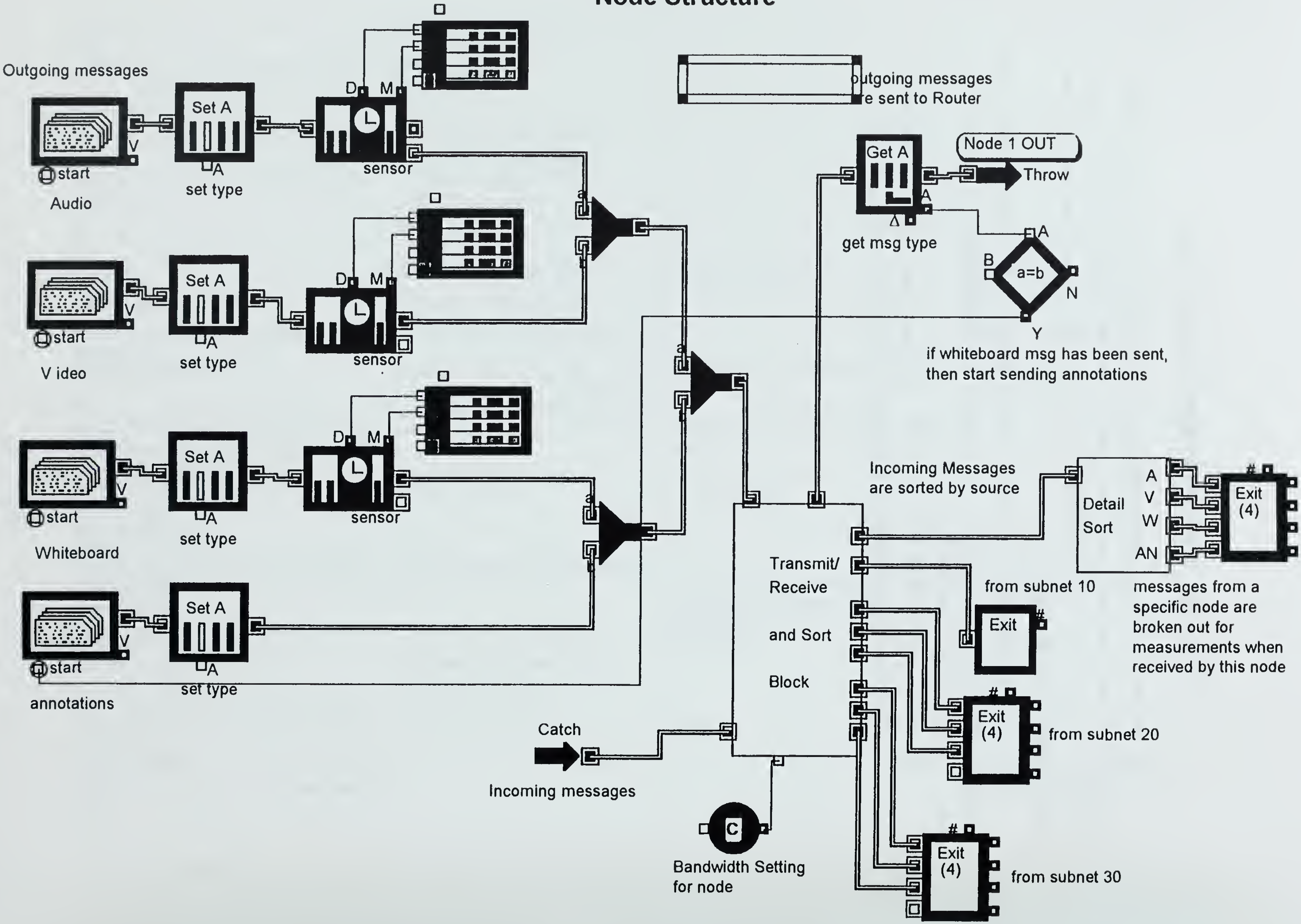
APPENDIX D: EXTEND MODEL STRUCTURES

The model structures are presented as printouts obtained from the Extend displays. Many levels of hierarchy can be built into a model and several pages are used to shown each level of the node and router structures, starting at the top levels and working down into the details of specific blocks.

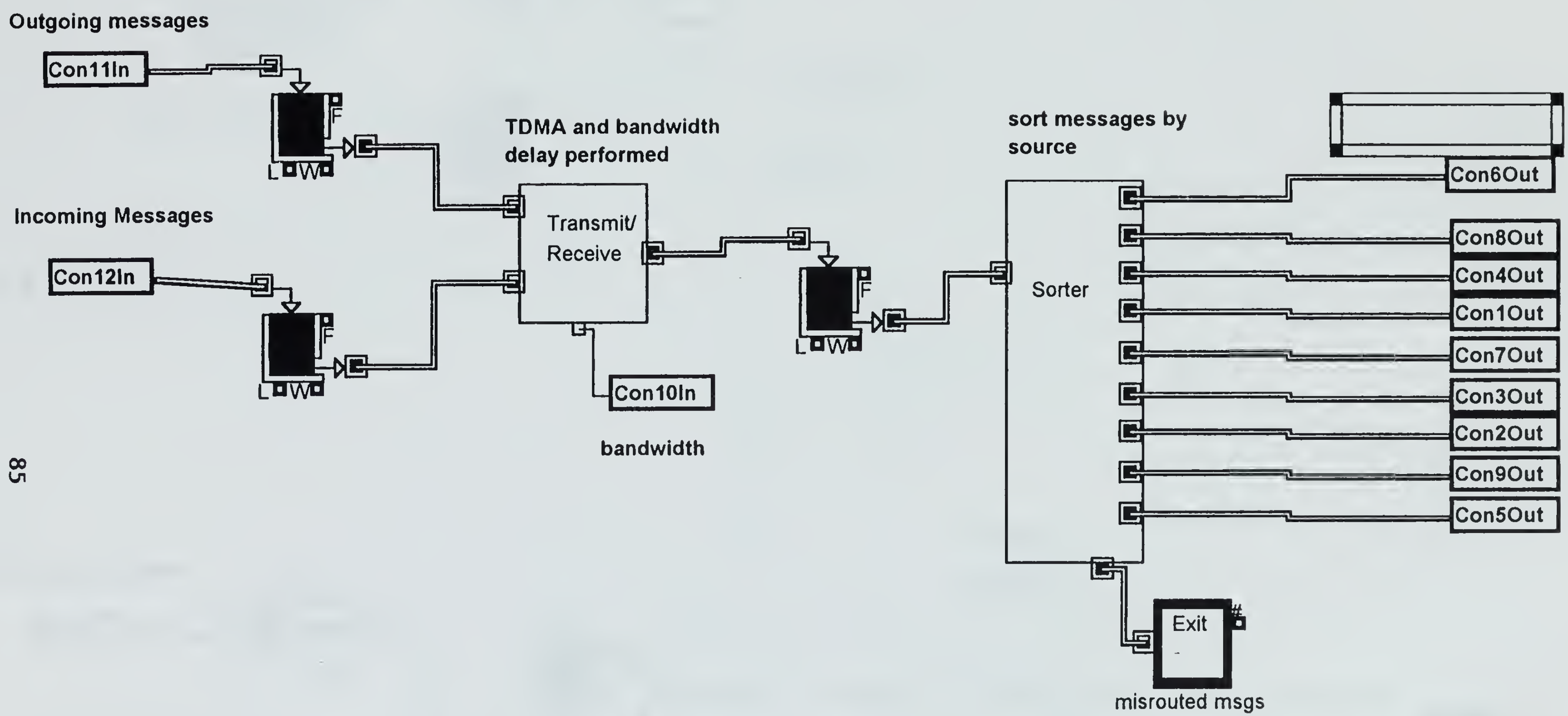
The node structure shown is that of Node 1 which sends out audio, video, and whiteboard messages with annotations. This basic structure was copied to represent the number of nodes in the scenario, from two to nine.

The router structure shown is that of the Multicast router with the "replicator" block. A Unicast router is achieved by disconnecting the replicator block in the model.

Node Structure

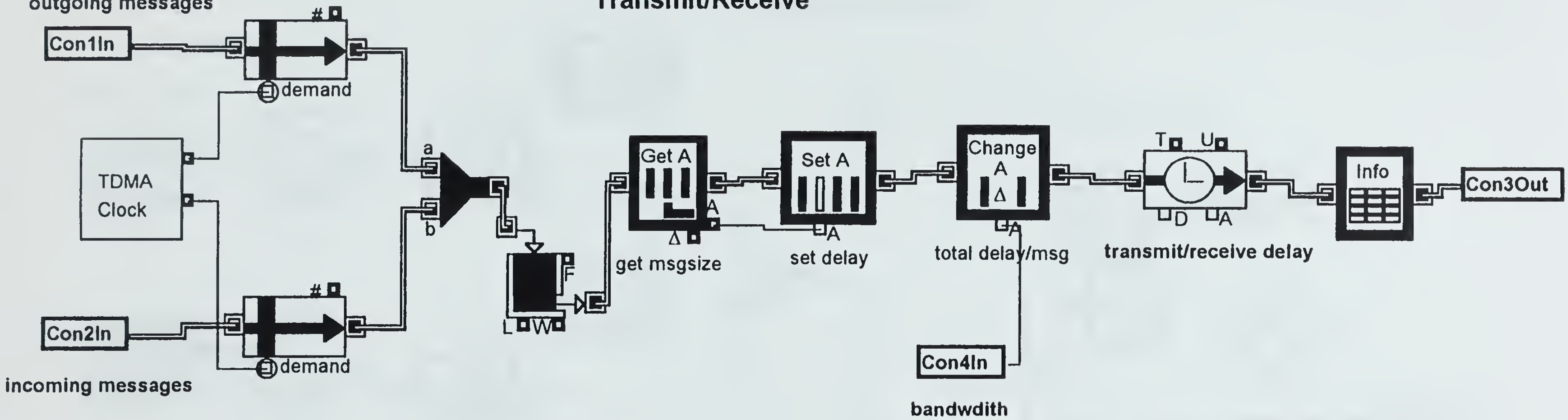


Transmit/Receive and Sort Block

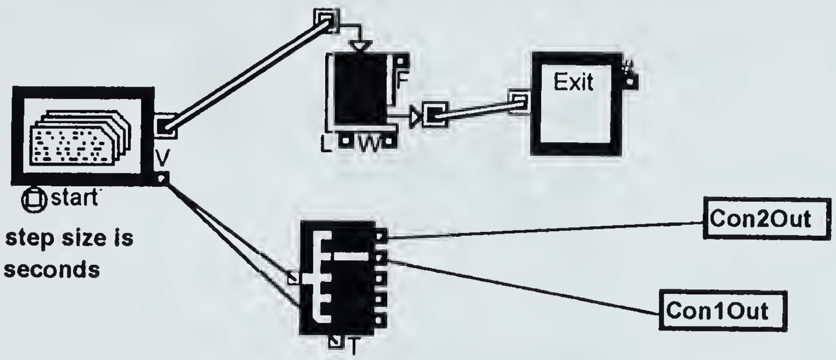


Node structure.MOX - 1

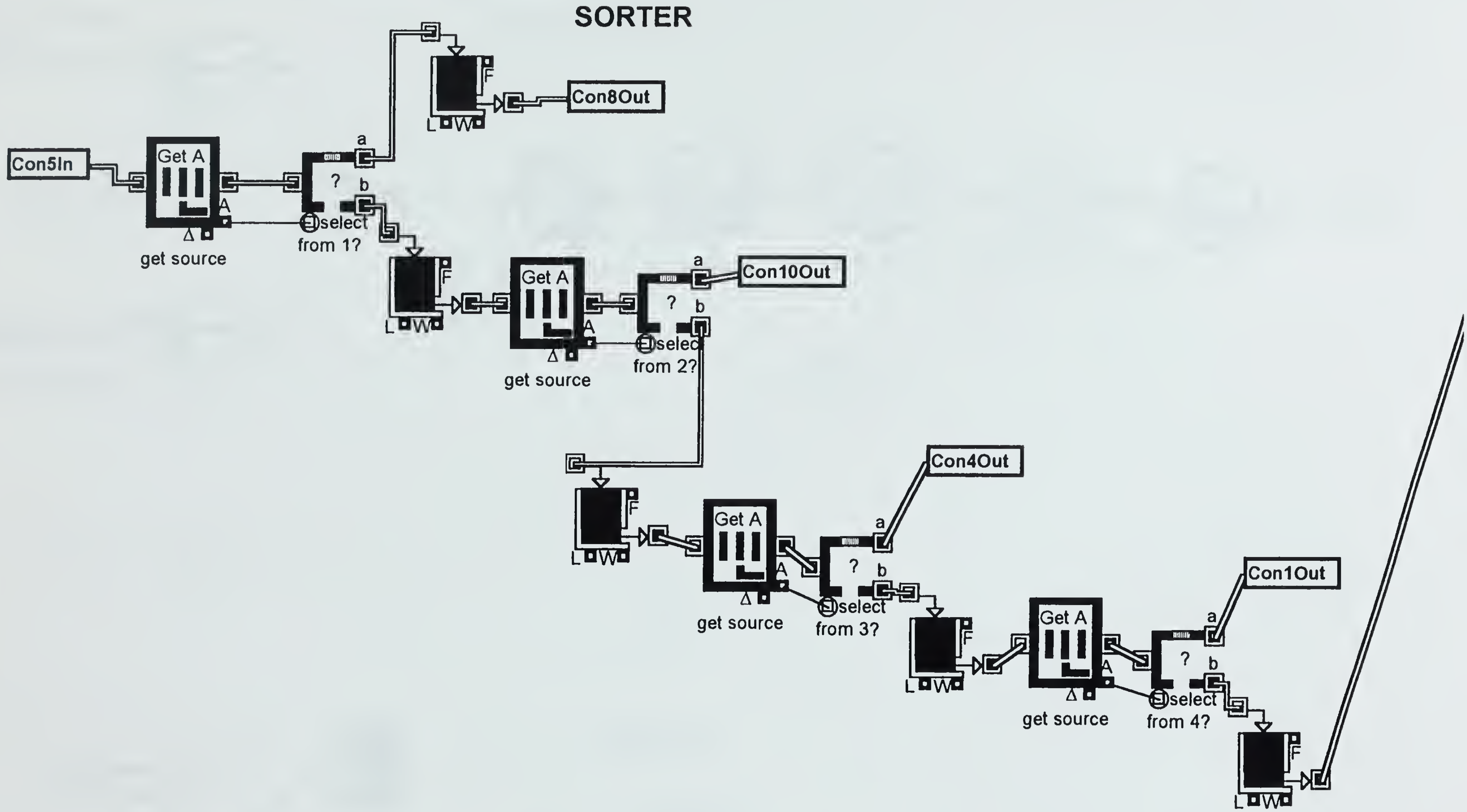
Transmit/Receive



Clock

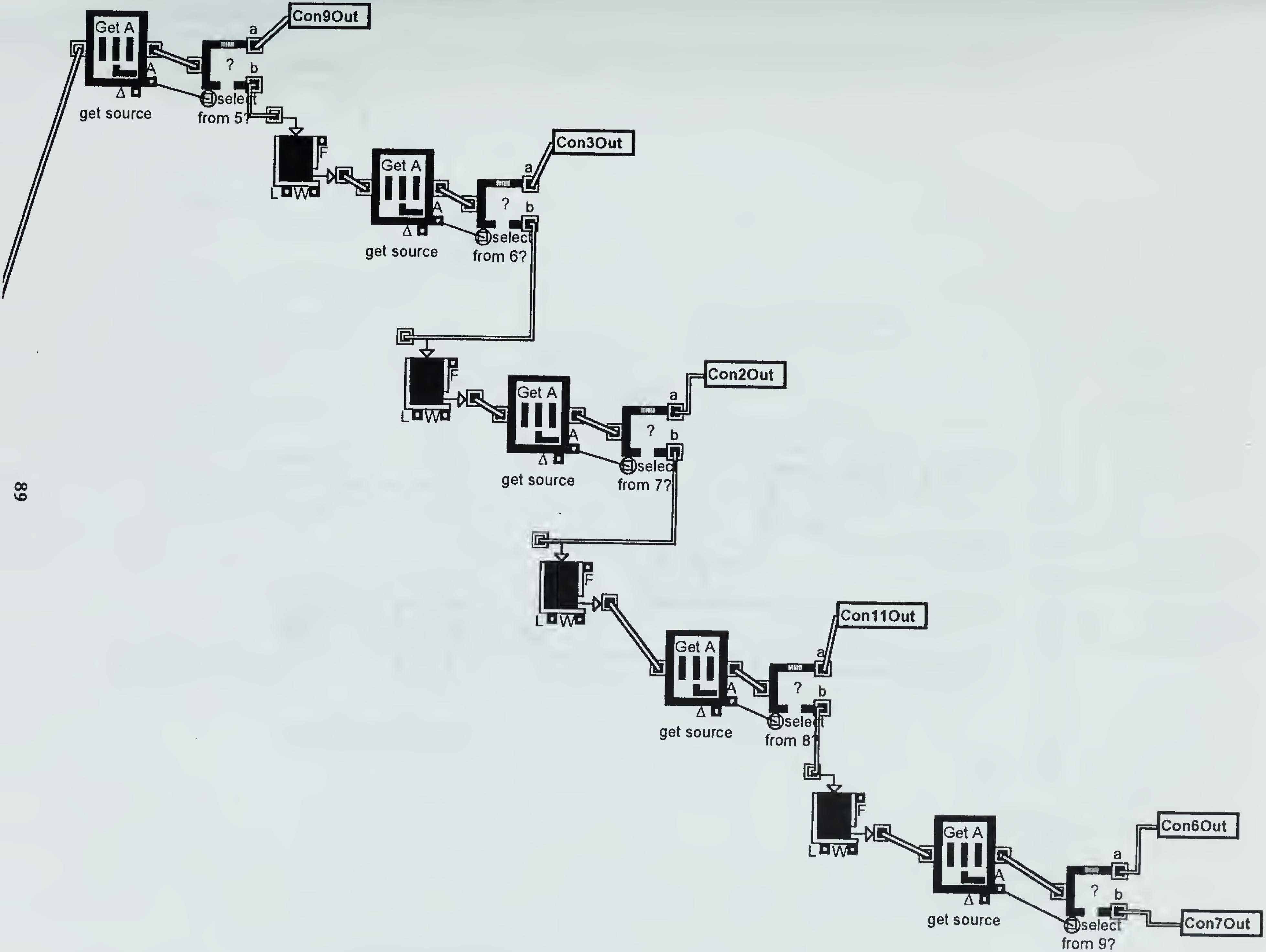


clock step size is
0.002 seconds



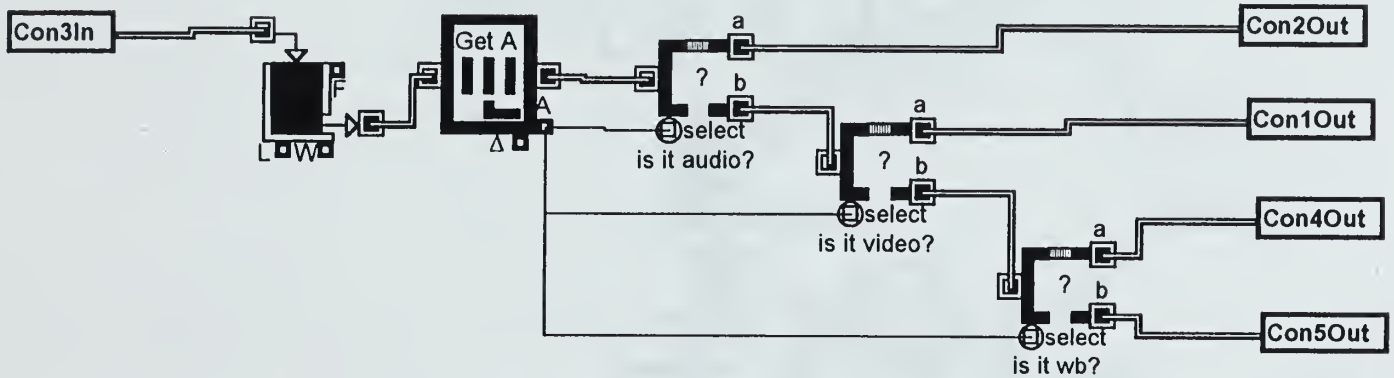
Node structure.MOX - 1

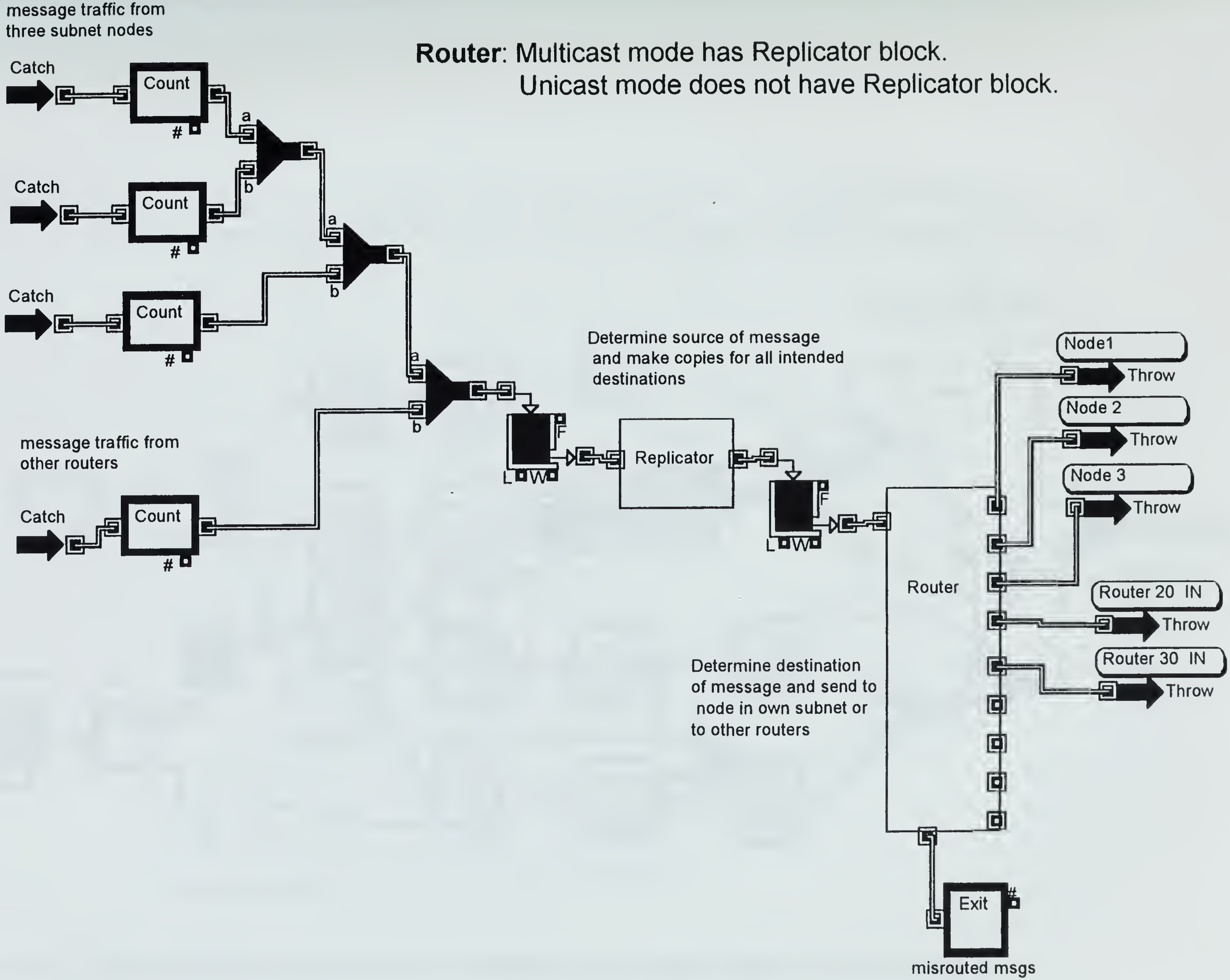
[315][1] filter



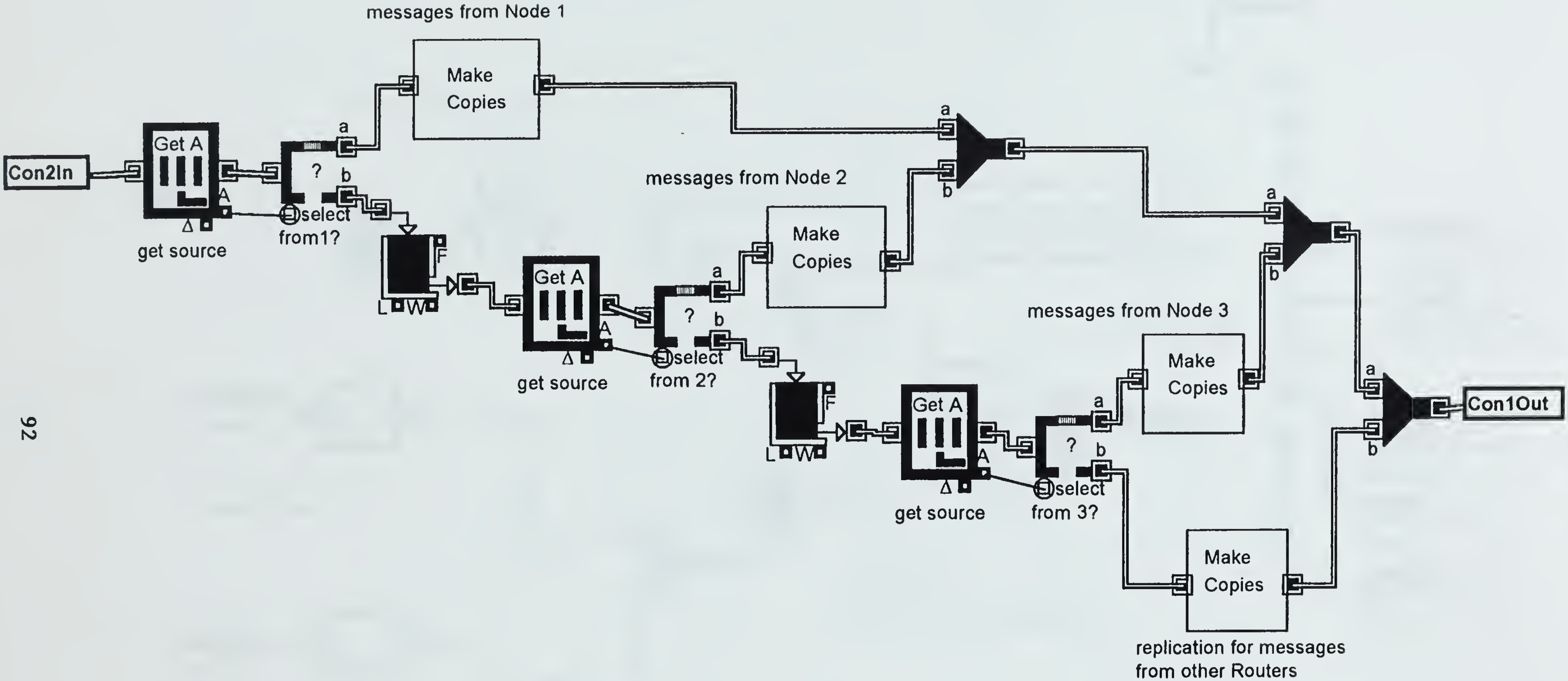
Node structure.MOX - 2

Detail Sort block



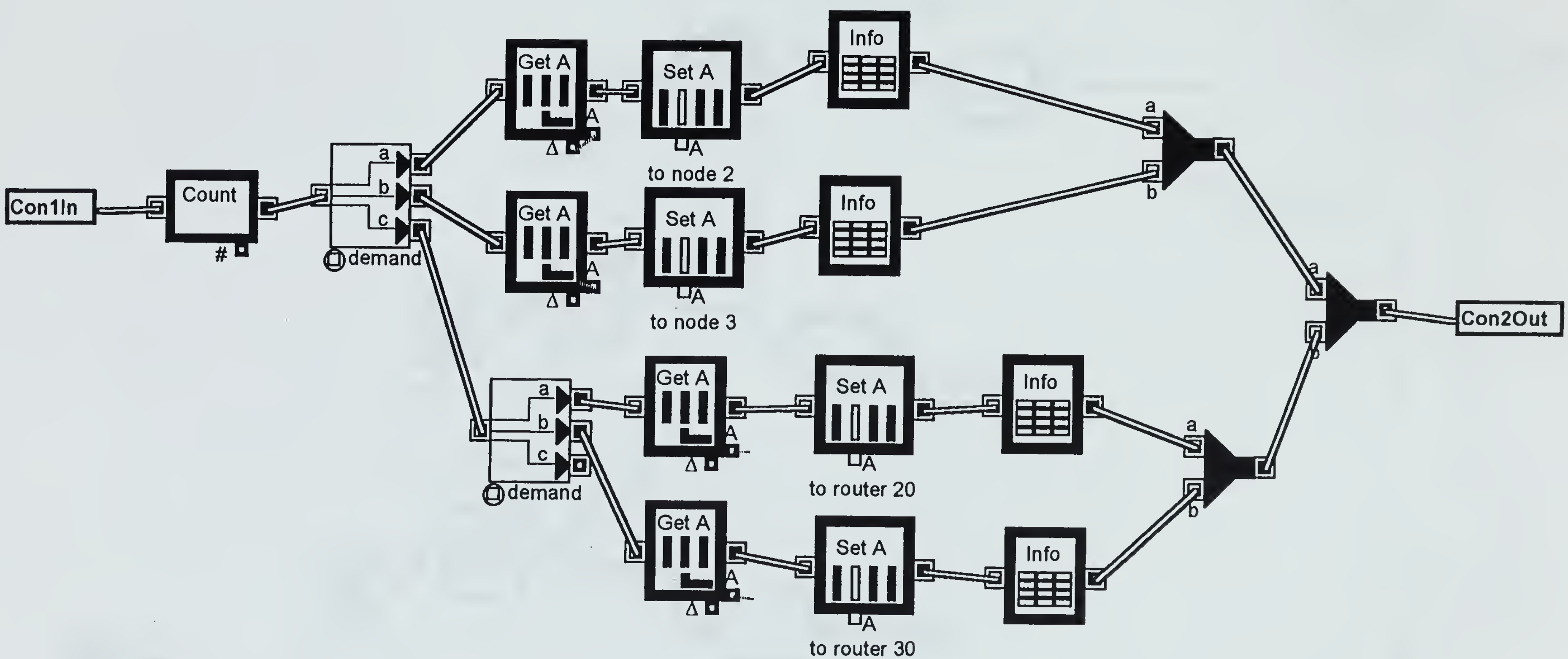

message traffic from
three subnet nodes
Router: Multicast mode has Replicator block.
Unicast mode does not have Replicator block.
Catch
Count
#
a
b
message traffic from
other routers
Determine source of message
and make copies for all intended
destinations
Replicator
L
W
F
Router
Determine destination
of message and send to
node in own subnet or
to other routers
Node1
Node 2
Node 3
Router 20 IN
Router 30 IN
Throw
Exit
misrouted msgs

Replicator: Determines which node sent the message then makes copies for all destinations.



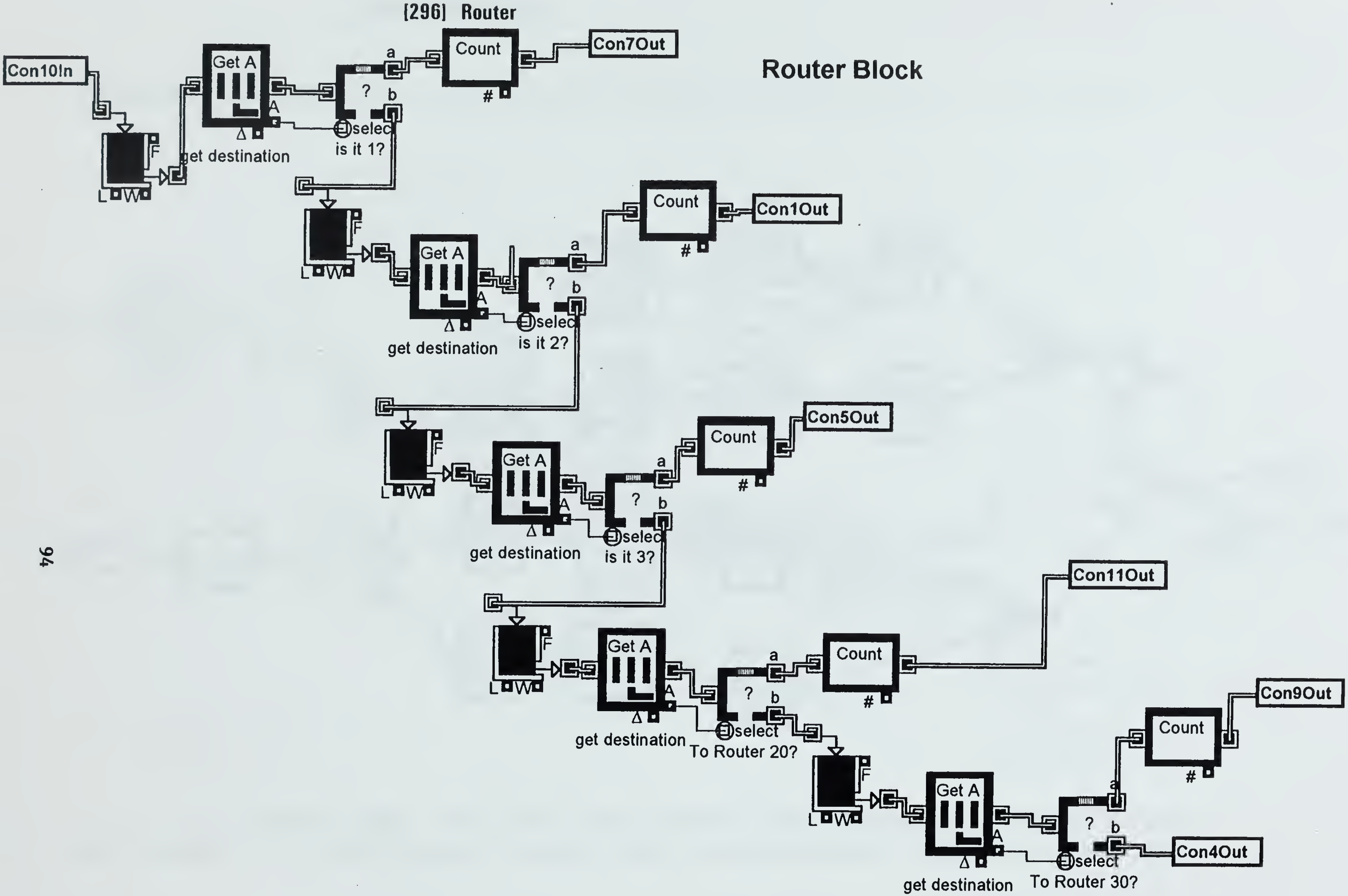
92

Make Copies: For a message from a specific node (in this case Node 1), replicate for distribution to other nodes in the subnet (node 2 and 3), and to other Routers (Routers 20 and 30).



Router Structure.MOX - 1

Router Block



APPENDIX E: EXTEND MODEL RUNS

The following matrices show the various combinations of parameters that were used and the resulting model runs that were executed.

Baseline Runs - 3 nodes

Run Number	session type	# nodes	Delivery	Bandwidth
111	text chat - high	3	unicast	384 kbps
112	audio - 14.4 kbps	3	unicast	384 kbps
113	audio - 64 kbps	3	unicast	384 kbps
114	video - low 4 fps + 14.4 kbps audio	3	unicast	384 kbps
115	video - low 4 fps + 64 kbps audio	3	unicast	384 kbps
116	video - high 15 fps + 14.4 kbps audio	3	unicast	384 kbps
117	video - high 15 fps + 64 kbps audio	3	unicast	384 kbps
118	wb + 14.4 kbps audio	3	unicast	384 kbps
119	wb + 64 kbps audio	3	unicast	384 kbps
120	wb + 4 fps video + 14.4 kbps audio	3	unicast	384 kbps
121	wb + 4 fps video + 64 kbps audio	3	unicast	384 kbps
122	wb + 15 fps video + 14.4 audio	3	unicast	384 kbps
123	wb + 15 fps video + 64 kbps audio	3	unicast	384 kbps
311	text chat - high	3	multicast	384 kbps
312	audio - 14.4 kbps	3	multicast	384 kbps
313	audio - 64 kbps	3	multicast	384 kbps
314	video - low 4 fps + 14.4 kbps audio	3	multicast	384 kbps
315	video - low 4 fps + 64 kbps audio	3	multicast	384 kbps
316	video - high 15 fps + 14.4 kbps audio	3	multicast	384 kbps
317	video - high 15 fps + 64 kbps audio	3	multicast	384 kbps
318	wb + 14.4 kbps audio	3	multicast	384 kbps
319	wb + 64 kbps audio	3	multicast	384 kbps
320	wb + 4 fps video + 14.4 kbps audio	3	multicast	384 kbps
321	wb + 4 fps video + 64 kbps audio	3	multicast	384 kbps
322	wb + 15 fps video + 14.4 audio	3	multicast	384 kbps
323	wb + 15 fps video + 64 kbps audio	3	multicast	384 kbps
511	text chat - high	3	unicast	128 kbps
512	audio - 14.4 kbps	3	unicast	128 kbps
513	audio - 64 kbps	3	unicast	128 kbps
514	video - low 4 fps + 14.4 kbps audio	3	unicast	128 kbps
515	video - low 4 fps + 64 kbps audio	3	unicast	128 kbps
516	video - high 15 fps + 14.4 kbps audio	3	unicast	128 kbps
517	video - high 15 fps + 64 kbps audio	3	unicast	128 kbps
518	wb + 14.4 kbps audio	3	unicast	128 kbps
519	wb + 64 kbps audio	3	unicast	128 kbps
520	wb + 4 fps video + 14.4 kbps audio	3	unicast	128 kbps
521	wb + 4 fps video + 64 kbps audio	3	unicast	128 kbps
522	wb + 15 fps video + 14.4 audio	3	unicast	128 kbps
523	wb + 15 fps video + 64 kbps audio	3	unicast	128 kbps
711	text chat - high	3	multicast	128 kbps
712	audio - 14.4 kbps	3	multicast	128 kbps
713	audio - 64 kbps	3	multicast	128 kbps
714	video - low 4 fps + 14.4 kbps audio	3	multicast	128 kbps
715	video - low 4 fps + 64 kbps audio	3	multicast	128 kbps
716	video - high 15 fps + 14.4 kbps audio	3	multicast	128 kbps
717	video - high 15 fps + 64 kbps audio	3	multicast	128 kbps
718	wb + 14.4 kbps audio	3	multicast	128 kbps
719	wb + 64 kbps audio	3	multicast	128 kbps
720	wb + 4 fps video + 14.4 kbps audio	3	multicast	128 kbps
721	wb + 4 fps video + 64 kbps audio	3	multicast	128 kbps
722	wb + 15 fps video + 14.4 audio	3	multicast	128 kbps
723	wb + 15 fps video + 64 kbps audio	3	multicast	128 kbps

Baseline Runs - 9 Nodes

Run Number	session type	# nodes	Delivery	Bandwidth
211	text chat - high	9	unicast	128 kbps
212	audio - 14.4 kbps	9	unicast	128 kbps
213	audio - 64 kbps	9	unicast	128 kbps
214	video - low 4 fps + 14.4 kbps audio	9	unicast	128 kbps
215	video - low 4 fps + 64 kbps audio	9	unicast	128 kbps
216	video - high 15 fps + 14.4 kbps audio	9	unicast	128 kbps
217	video - high 15 fps + 64 kbps audio	9	unicast	128 kbps
218	wb + 14.4 audio	9	unicast	128 kbps
219	wb + 64 kbps audio	9	unicast	128 kbps
220	wb + 4 fps video + 14.4 kbps audio	9	unicast	128 kbps
221	wb + 4 fps video + 64 kbps audio	9	unicast	128 kbps
222	wb + 15 fps video + 14.4 audio	9	unicast	128 kbps
223	wb + 15 fps video + 64 kbps audio	9	unicast	128 kbps
411	text chat - high	9	multicast	128 kbps
412	audio - 14.4 kbps	9	multicast	128 kbps
413	audio - 64 kbps	9	multicast	128 kbps
414	video - low 4 fps + 14.4 kbps audio	9	multicast	128 kbps
415	video - low 4 fps + 64 kbps audio	9	multicast	128 kbps
416	video - high 15 fps + 14.4 kbps audio	9	multicast	128 kbps
417	video - high 15 fps + 64 kbps audio	9	multicast	128 kbps
418	wb + 14.4 kbps audio	9	multicast	128 kbps
419	wb + 64 kbps audio	9	multicast	128 kbps
420	wb + 4 fps video + 14.4 kbps audio	9	multicast	128 kbps
421	wb + 4 fps video + 64 kbps audio	9	multicast	128 kbps
422	wb + 15 fps video + 14.4 audio	9	multicast	128 kbps
423	wb + 15 fps video + 64 kbps audio	9	multicast	128 kbps
611	text chat - high	9	unicast	384 kbps
612	audio - 14.4 kbps	9	unicast	384 kbps
613	audio - 64 kbps	9	unicast	384 kbps
614	video - low 4 fps + 14.4 kbps audio	9	unicast	384 kbps
615	video - low 4 fps + 64 kbps audio	9	unicast	384 kbps
616	video - high 15 fps + 14.4 kbps audio	9	unicast	384 kbps
617	video - high 15 fps + 64 kbps audio	9	unicast	384 kbps
618	wb + 14.4 audio	9	unicast	384 kbps
619	wb + 64 kbps audio	9	unicast	384 kbps
620	wb + 4 fps video + 14.4 kbps audio	9	unicast	384 kbps
621	wb + 4 fps video + 64 kbps audio	9	unicast	384 kbps
622	wb + 15 fps video + 14.4 audio	9	unicast	384 kbps
623	wb + 15 fps video + 64 kbps audio	9	unicast	384 kbps
811	text chat - high	9	multicast	384 kbps
812	audio - 14.4 kbps	9	multicast	384 kbps
813	audio - 64 kbps	9	multicast	384 kbps
814	video - low 4 fps + 14.4 kbps audio	9	multicast	384 kbps
815	video - low 4 fps + 64 kbps audio	9	multicast	384 kbps
816	video - high 15 fps + 14.4 kbps audio	9	multicast	384 kbps
817	video - high 15 fps + 64 kbps audio	9	multicast	384 kbps
818	wb + 14.4 kbps audio	9	multicast	384 kbps
819	wb + 64 kbps audio	9	multicast	384 kbps
820	wb + 4 fps video + 14.4 kbps audio	9	multicast	384 kbps
821	wb + 4 fps video + 64 kbps audio	9	multicast	384 kbps
822	wb + 15 fps video + 14.4 audio	9	multicast	384 kbps
823	wb + 15 fps video + 64 kbps audio	9	multicast	384 kbps

Focused Runs

Run Number	session type	# nodes	Delivery	Bandwidth
2 NODES				
14	video - low 4 fps + 14.4 kbps audio	2	unicast	128 kbps
14b	video - low 4 fps + 14.4 kbps audio	2	unicast	384 kbps
14c	video - low 4 fps + 14.4 kbps audio	2	unicast	256 kbps
18	wb + 14.4 kbps audio	2	unicast	128 kbps
18b	wb + 14.4 kbps audio	2	unicast	384 kbps
18c	wb + 14.4 kbps audio	2	unicast	256 kbps
20	wb + 4 fps video + 14.4 kbps audio	2	unicast	128 kbps
20b	wb + 4 fps video + 14.4 kbps audio	2	unicast	384 kbps
20c	wb + 4 fps video + 14.4 kbps audio	2	unicast	256 kbps
3 NODES				
514	video - low 4 fps + 14.4 kbps audio	3	unicast	128 kbps
114	video - low 4 fps + 14.4 kbps audio	3	unicast	384 kbps
1111	video - low 4 fps + 14.4 kbps audio	3	unicast	256 kbps
518	wb + 14.4 kbps audio	3	unicast	128 kbps
118	wb + 14.4 kbps audio	3	unicast	384 kbps
1115	wb + 14.4 kbps audio	3	unicast	256 kbps
520	wb + 4 fps video + 14.4 kbps audio	3	unicast	128 kbps
120	wb + 4 fps video + 14.4 kbps audio	3	unicast	384 kbps
1119	wb + 4 fps video + 14.4 kbps audio	3	unicast	256 kbps
714	video - low 4 fps + 14.4 kbps audio	3	multicast	128 kbps
314	video - low 4 fps + 14.4 kbps audio	3	multicast	384 kbps
1113	video - low 4 fps + 14.4 kbps audio	3	multicast	256 kbps
718	wb + 14.4 kbps audio	3	multicast	128 kbps
318	wb + 14.4 kbps audio	3	multicast	384 kbps
1117	wb + 14.4 kbps audio	3	multicast	256 kbps
720	wb + 4 fps video + 14.4 kbps audio	3	multicast	128 kbps
320	wb + 4 fps video + 14.4 kbps audio	3	multicast	384 kbps
1121	wb + 4 fps video + 14.4 kbps audio	3	multicast	256 kbps

6 NODES				
64	video - low 4 fps + 14.4 kbps audio	6	unicast	128 kbps
64b	video - low 4 fps + 14.4 kbps audio	6	unicast	384 kbps
64c	video - low 4 fps + 14.4 kbps audio	6	unicast	256 kbps
68	wb + 14.4 kbps audio	6	unicast	128 kbps
68b	wb + 14.4 kbps audio	6	unicast	384 kbps
68c	wb + 14.4 kbps audio	6	unicast	256 kbps
70	wb + 4 fps video + 14.4 kbps audio	6	unicast	128 kbps
70b	wb + 4 fps video + 14.4 kbps audio	6	unicast	384 kbps
70c	wb + 4 fps video + 14.4 kbps audio	6	unicast	256 kbps
6014	video - low 4 fps + 14.4 kbps audio	6	multicast	128 kbps
6014b	video - low 4 fps + 14.4 kbps audio	6	multicast	384 kbps
64c	video - low 4 fps + 14.4 kbps audio	6	multicast	256 kbps
6018	wb + 14.4 kbps audio	6	multicast	128 kbps
6018b	wb + 14.4 kbps audio	6	multicast	384 kbps
6018c	wb + 14.4 kbps audio	6	multicast	256 kbps
6020	wb + 4 fps video + 14.4 kbps audio	6	multicast	128 kbps
6020b	wb + 4 fps video + 14.4 kbps audio	6	multicast	384 kbps
6020c	wb + 4 fps video + 14.4 kbps audio	6	multicast	256 kbps
9 NODES				
214	video - low 4 fps + 14.4 kbps audio	9	unicast	128 kbps
614	video - low 4 fps + 14.4 kbps audio	9	unicast	384 kbps
1112	video - low 4 fps + 14.4 kbps audio	9	unicast	256 kbps
218	wb + 14.4 kbps audio	9	unicast	128 kbps
618	wb + 14.4 kbps audio	9	unicast	384 kbps
1116	wb + 14.4 kbps audio	9	unicast	256 kbps
220	wb + 4 fps video + 14.4 kbps audio	9	unicast	128 kbps
620	wb + 4 fps video + 14.4 kbps audio	9	unicast	384 kbps
1120	wb + 4 fps video + 14.4 kbps audio	9	unicast	256 kbps
414	video - low 4 fps + 14.4 kbps audio	9	multicast	128 kbps
814	video - low 4 fps + 14.4 kbps audio	9	multicast	384 kbps
1114	video - low 4 fps + 14.4 kbps audio	9	multicast	256 kbps
418	wb + 14.4 kbps audio	9	multicast	128 kbps
818	wb + 14.4 kbps audio	9	multicast	384 kbps
1118	wb + 14.4 kbps audio	9	multicast	256 kbps
420	wb + 4 fps video + 14.4 kbps audio	9	multicast	128 kbps
820	wb + 4 fps video + 14.4 kbps audio	9	multicast	384 kbps
1122	wb + 4 fps video + 14.4 kbps audio	9	multicast	256 kbps

Point to Point Scenario				
Run Number	session type	# nodes	Delivery	Bandwidth
14	video - low 4 fps + 14.4 kbps audio	2	unicast	128 kbps
14b	video - low 4 fps + 14.4 kbps audio	2	unicast	384 kbps
14c	video - low 4 fps + 14.4 kbps audio	2	unicast	256 kbps
14d	video - low 4 fps + 14.4 kbps audio	2	unicast	64 kbps
18	wb + 14.4 kbps audio	2	unicast	128 kbps
18b	wb + 14.4 kbps audio	2	unicast	384 kbps
18c	wb + 14.4 kbps audio	2	unicast	256 kbps
18d	wb + 14.4 kbps audio	2	unicast	64 kbps
20	wb + 4 fps video + 14.4 kbps audio	2	unicast	128 kbps
20b	wb + 4 fps video + 14.4 kbps audio	2	unicast	384 kbps
20c	wb + 4 fps video + 14.4 kbps audio	2	unicast	256 kbps
20d	wb + 4 fps video + 14.4 kbps audio	2	unicast	64 kbps
Satellite as Multicast Router				
Run Number	**session type**	**# nodes**	**Delivery**	**Bandwidth**
1023	video - low 4 fps + 14.4 kbps audio	3	multicast	128
1023b	video - low 4 fps + 14.4 kbps audio	3	multicast	256
1024	video - low 4 fps + 14.4 kbps audio	3	multicast	384
1025	wb + 14.4 kbps audio	3	multicast	128
1025b	wb + 14.4 kbps audio	3	multicast	256
1026	wb + 14.4 kbps audio	3	multicast	384
1031	wb + 4 fps video + 14.4 kbps audio	3	multicast	128
1031b	wb + 4 fps video + 14.4 kbps audio	3	multicast	256
1031c	wb + 4 fps video + 14.4 kbps audio	3	multicast	384
Satellite Ashore				
1027	video - low 4 fps + 14.4 kbps audio	3	multicast	128
1027b	video - low 4 fps + 14.4 kbps audio	3	multicast	256
1028	video - low 4 fps + 14.4 kbps audio	3	multicast	384
1029	wb + 14.4 kbps audio	3	multicast	128
1029b	wb + 14.4 kbps audio	3	multicast	256
1030	wb + 14.4 kbps audio	3	multicast	384
1032	wb + 4 fps video + 14.4 kbps audio	3	multicast	128
1032b	wb + 4 fps video + 14.4 kbps audio	3	multicast	256
1032c	wb + 4 fps video + 14.4 kbps audio	3	multicast	384

APPENDIX F: EXTEND MODEL RESULTS

The following spreadsheets contain the data that was collected from the Extend model runs. Additional rearrangements were performed in order to generate the charts presented in Chapter V.

UNICAST, 128 kbps

	A	B	C	D	E	F	G	H
1	**Unicast & 128 kbps**							
2								
3	**Text Chat**	Avg Delay						
4	3 node	0.0958	0.0958	0.0958	0.0958			
5	9 node	0.324667	0.314	0.314	0.346			
6								
7	**Audio (14.4 kbps)**	Avg Delay						
8	3 node	0.339667	0.339	0.341	0.339			
9	9 node	28.45333	28.62	28.93	27.81			
10								
11	**Audio (64 kbps)**	Avg Delay						
12	3 node	31.739	32.423	31.397	31.397			
13	9 node	47.96033	53.877	54.127	35.877			
14								
15	**Video (4 fps) + Audio (14.4 kbps)**	Avg Delay						
16	3 node	5.798833	5.685	6.047	5.767	5.968	5.801	5.525
17	9 node	46.11217	48.484	48.254	43.803	47.62	45.169	43.343
18								
19	3 node Audio	5.833	5.685	6.047	5.767			
20	3 node Video	5.764667	5.968	5.801	5.525			
21	9 node Audio	46.847	48.484	48.254	43.803			
22	9 node Video	45.37733	47.62	45.169	43.343			
23								
24	**Video (4 fps) + Audio (64 kbps)**	Avg Delay						
25	3 node	37.5875	37.756	38.411	37.049	38.184	36.882	37.243
26	9 node	47.6785	53.9	48.724	44.704	49.449	48.882	40.412
27								
28	3 node Audio	37.73867	37.756	38.411	37.049			
29	3 node Video	37.43633	38.184	36.882	37.243			
30	9 node Audio	49.10933	53.9	48.724	44.704			
31	9 node Video	46.24767	49.449	48.882	40.412			
32								
33	**Video (15 fps) + Audio (14.4 kbps)**	Avg Delay						
34	3 node	39.35867	38.725	40.601	39.187	38.676	40.34	38.623
35	9 node	54.05483	63.739	51.897	47.517	62.383	52.491	46.302
36								
37	3 node Audio	39.50433	38.725	40.601	39.187			
38	3 node Video	39.213	38.676	40.34	38.623			
39	9 node Audio	54.38433	63.739	51.897	47.517			
40	9 node Video	53.72533	62.383	52.491	46.302			

UNICAST, 128 kbps

	A	B	C	D	E	F	G	H
41								
42	**Video (15 fps) + Audio (64 kbps)**	Avg Delay						
43	3 node	44.9895	46.064	45.301	45.978	44.739	43.562	44.293
44	9 node	60.861	67.331	77.084	24.071	63.955	77.678	55.047
45								
46	3 node Audio	45.781	46.064	45.301	45.978			
47	3 node Video	44.198	44.739	43.562	44.293			
48	9 node Audio	56.162	67.331	77.084	24.071			
49	9 node Video	65.56	63.955	77.678	55.047			
50								
51	**Wb + Audio (14.4 kbps)**	Avg Delay						
52	3 node Audio	1.258333	1.741	0.877	1.157			
53	3 node Wb	11.1895	13.427	8.952				
54	9 node Audio	51.54333	68.347	33.204	53.079			
55	9 node Wb	37.08933	56.283	18.089	36.896			
56								
57	**Wb + Audio (64 kbps)**	Avg Delay						
58	3 node Audio	38.459	42.754	33.212	39.411			
59	3 node Wb	13.477	15.977	10.977				
60	9 node Audio	69.83933	**100**	42.115	67.403	(C:no audio delivered)		
61	9 node Wb	83.82567	**100**	51.477	**100**	(C,E: no wb delivered)		
62								
63	**Wb + Video (4 fps) + Audio (14.4 kbps)**	Avg Delay						
64	3 node	15.63583	16.346	13.066	17.802	16.125	12.778	17.698
65	3 node Wb	11.654	9.289	14.019				
66	9 node	69.94567	**100**	44.451	65.79	**100**	44.074	65.359
67	9 node Wb	67.849	**100**	32.11	71.437	C: no wb delivered)		
68								
69	3 node Audio	15.738	16.346	13.066	17.802			
70	3 node Video	15.53367	16.125	12.778	17.698			
71	9 node Audio	70.08033	**100**	44.451	65.79	(C: no audio delivered)		
72	9 node Video	69.811	**100**	44.074	65.359	(C: no video delivered)		
73								

UNICAST, 128 kbps

	A	B	C	D	E	F	G	H
74	**Wb + Video (4 fps) + Audio (64 kbps)**	Avg Delay						
75	3 node	44.234	51.628	40.632	42.744	49.431	39.394	41.575
76	3 node Wb	17.1455	13.195	21.096				
77	9 node	70.16167	**100**	44.44	68.206	**100**	42.185	66.139
78	9 node Wb	88.403	**100**	65.209	**100**	(C,E: no wb delivered)		
79								
80	3 node Audio	45.00133	51.628	40.632	42.744			
81	3 node Video	43.46667	49.431	39.394	41.575			
82	9 node Audio	70.882	**100**	44.44	68.206	(C:no audio delivered)		
83	9 node Video	69.44133	**100**	42.185	66.139	(C:no video delivered)		
84								
85	**Wb + Video (15 fps) + Audio (14.4 kbps)**	Avg Delay						
86	3 node	45.517	52.23	40.852	44.229	51.245	40.672	43.874
87	3 node Wb	19.908	15.669	24.147				
88	9 node	71.34217	**100**	30.942	73.417	**100**	51.449	72.245
89	9 node Wb	89.35467	**100**	68.064	**100**	(C, E: no wb delivered)		
90								
91	3 node Audio	45.77033	52.23	40.852	44.229			
92	3 node Video	45.26367	51.245	40.672	43.874			
93	9 node Audio	68.11967	**100**	30.942	73.417	(C:no audio delivered)		
94	9 node Video	74.56467	**100**	51.449	72.245	(C:no video delivered)		
95								
96	**Wb + Video (15 fps) + Audio (64 kbps)**	Avg Delay						
97	**3 node**	49.8175	60.019	43.602	45.313	55.764	46.498	47.709
98	3 node Wb	26.9515	20.387	33.516				
99	9 node	65.27333	**100**	27.353	79.064	**100**	18.1	67.123
100	9 node Wb	100	**100**	**100**	**100**	(C, D, E:no Wb delivered)		
101								
102	3 node Audio	49.64467	60.019	43.602	45.313			
103	3 node Video	49.99033	55.764	46.498	47.709			
104	9 node Audio	68.80567	**100**	27.353	79.064	(C:no audio delivered)		
105	9 node Video	61.741	**100**	18.1	67.123	(C:no video delivered)		
106								

Unicast, 384 kbps

Unicast + 384 kbps							
Text Chat	Avg Delay						
3 node	0.033	0.033	0.033	0.033			
9 node	0.109667	0.106	0.106	0.117			
Audio (14.4 kbps)	Avg Delay						
3 node	0.1145	0.1145	0.1145	0.1145			
9 node	0.439333	0.452	0.377	0.489			
Audio (64 kbps)	Avg Delay						
3 node	0.557333	0.668	0.502	0.502			
9 node	38.84433	40.249	38.189	38.095			
Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.272833	0.22	0.31	0.326	0.273	0.273	0.235
9 node	20.4265	20.929	20.2	20.295	20.707	20.335	20.093
3 node Audio	0.285333	0.22	0.31	0.326			
3 node Video	0.260333	0.273	0.273	0.235			
9 node Audio	20.47467	20.929	20.2	20.295			
9 node Video	20.37833	20.707	20.335	20.093			
Video (4 fps) + Audio (64 kbps)	Avg Delay						
3 node	0.632833	0.608	0.828	0.713	0.66	0.494	0.494
9 node	42.33767	44.804	40.549	41.162	43.855	40.767	42.889
3 node Audio	0.716333	0.608	0.828	0.713			
3 node Video	0.549333	0.66	0.494	0.494			
9 node Audio	42.17167	44.804	40.549	41.162			
9 node Video	42.50367	43.855	40.767	42.889			
Video (15 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.708833	0.511	0.746	0.907	0.709	0.709	0.671
9 node	43.916	44.588	43.265	43.978	44.181	43.907	43.577
3 node Audio	0.721333	0.511	0.746	0.907			
3 node Video	0.696333	0.709	0.709	0.671			
9 node Audio	43.94367	44.588	43.265	43.978			
9 node Video	43.88833	44.181	43.907	43.577			

Unicast, 384 kbps

Video (15 fps) + Audio (64 kbps)	Avg Delay						
3 node	20.82617	20.757	20.898	20.969	21.188	20.621	20.524
9 node	48.83283	52.74	49.501	44.637	52.272	50.362	43.485
3 node Audio	20.87467	20.757	20.898	20.969			
3 node Video	20.77767	21.188	20.621	20.524			
9 node Audio	48.95933	52.74	49.501	44.637			
9 node Video	48.70633	52.272	50.362	43.485			
Wb + Audio (14.4 kbps)	Avg Delay						
3 node Audio	0.208	0.252	0.185	0.187			
3 node Wb	3.731	4.477	2.985				
9 node Audio	1.788333	2.474	0.408	2.483			
9 node Wb	9.230667	13.794	4.794	9.104			
Wb + Audio (64 kbps)	Avg Delay						
3 node Audio	0.711333	0.739	0.738	0.657			
3 node Wb	3.7355	4.477	2.994				
9 node Audio	46.39833	54.87	38.448	45.877			
9 node Wb	18.38233	27.66	9.16	18.327			
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.3465	0.359	0.383	0.419	0.293	0.294	0.331
3 node Wb	3.8565	3.039	4.674				
9 node	28.55033	33.444	21.763	30.6	33.362	21.689	30.444
9 node Wb	11.164	16.773	5.828	10.891			
3 node Audio	0.387	0.359	0.383	0.419			
3 node Video	0.306	0.293	0.294	0.331			
9 node Audio	28.60233	33.444	21.763	30.6			
9 node Video	28.49833	33.362	21.689	30.444			
Wb + Video (4 fps) + Audio (64 kbps)	Avg Delay						
3 node	0.953333	1.038	0.952	1.208	0.813	0.726	0.983
3 node Wb	4.0425	3.152	4.933				
9 node	50.88283	61.593	43.849	48.126	60.982	43.302	47.445
9 node Wb	20.98833	31.999	10.159	20.807			
3 node Audio	1.066	1.038	0.952	1.208			
3 node Video	0.840667	0.813	0.726	0.983			
9 node Audio	51.18933	61.593	43.849	48.126			
9 node Video	50.57633	60.982	43.302	47.445			

Unicast, 384 kbps

Wb + Video (15 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	1.521833	1.532	1.267	1.941	1.455	1.138	1.798
3 node Wb	4.0825	3.2	4.965				
9 node	51.51883	61.464	43.816	49.797	61.217	43.352	49.467
9 node Wb	22.61067	33.758	10.678	23.396			
3 node Audio	1.58	1.532	1.267	1.941			
3 node Video	1.463667	1.455	1.138	1.798			
9 node Audio	51.69233	61.464	43.816	49.797			
9 node Video	51.34533	61.217	43.352	49.467			
Wb + Video (15 fps) + Audio (64 kbps)	Avg Delay						
3 node	23.334	24.535	22.36	23.167	24.194	22.043	23.705
3 node Wb	4.5255	3.682	5.369				
9 node	60.50267	77.722	48.769	56.379	77.506	47.352	55.288
9 node Wb	33.34167	50.724	15.716	33.585			
3 node Audio	23.354	24.535	22.36	23.167			
3 node Video	23.314	24.194	22.043	23.705			
9 node Audio	60.95667	77.722	48.769	56.379			
9 node Video	60.04867	77.506	47.352	55.288			

	A	B	C	D	E	F	G	H	I
1	**Multicast & 128 kbps**								
2									
3	**Text Chat**	Avg Delay							
4	3 node	0.074933	0.0958	0.0645	0.0645				
5	9 node	0.158333	0.096	0.252	0.127				
6									
7	**Audio (14.4 kbps)**	Avg Delay							
8	3 node	0.264333	0.227	0.339	0.227				
9	9 node	1.284333	1.099	1.543	1.211				
10									
11	**Audio (64 kbps)**	Avg Delay							
12	3 node	20.37333	20.313	20.494	20.313				
13	9 node	42.73733	41.904	43.904	42.404				
14									
15	**Video (4 fps) + Audio (14.4 kbps)**	Avg Delay							
16	3 node	0.609833	0.7	0.813	0.7	0.429	0.588	0.429	
17	9 node	31.6245	31.914	32.281	31.369	30.895	31.226	32.062	
18									
19	3 node Audio	0.737667	0.7	0.813	0.7				
20	3 node Video	0.482	0.429	0.588	0.429				
21	9 node Audio	31.85467	31.914	32.281	31.369				
22	9 node Video	31.39433	30.895	31.226	32.062				
23									
24	**Video (4 fps) + Audio (64 kbps)**	Avg Delay							
25	3 node	29.09283	29.104	29.822	29.366	29.486	28.409	28.37	
26	9 node	43.2155	43.895	43.385	43.392	43.32	41.674	43.627	
27									
28	3 node Audio	29.43067	29.104	29.822	29.366				
29	3 node Video	28.755	29.486	28.409	28.37				
30	9 node Audio	43.55733	43.895	43.385	43.392				
31	9 node Video	42.87367	43.32	41.674	43.627				
32									
33	**Video (15 fps) + Audio (14.4 kbps)**	Avg Delay							
34	3 node	31.20433	31.485	31.598	31.485	30.688	31.282	30.688	
35	9 node	39.531	39.216	39.495	38.408	40.07	41.258	38.739	
36									
37	3 node Audio	31.52267	31.485	31.598	31.485				
38	3 node Video	30.886	30.688	31.282	30.688				
39	9 node Audio	39.03967	39.216	39.495	38.408				
40	9 node Video	40.02233	40.07	41.258	38.739				
41									

	A	B	C	D	E	F	G	H	I
42	**Video (15 fps) + Audio (64 kbps)**	Avg Delay							
43	3 node	39.83083	40.519	41.019	40.519	38.778	39.372	38.778	
44	9 node	46.85717	48.824	50.344	43.005	43.983	45.233	49.754	
45									
46	3 node Audio	40.68567	40.519	41.019	40.519				
47	3 node Video	38.976	38.778	39.372	38.778				
48	9 node Audio	47.391	48.824	50.344	43.005				
49	9 node Video	46.32333	43.983	45.233	49.754				
50									
51	**Wb + Audio (14.4 kbps)**	Avg Delay							
52	3 node Audio	0.613667	0.784	0.51	0.547				
53	3 node Wb	8.95	8.95	8.95					
54	9 node Audio	6.906333	6.689	7.199	6.831				
55	9 node Wb	9.378	9.376	9.379	9.379				
56									
57	**Wb + Audio (64 kbps)**	Avg Delay							
58	3 node Audio	24.971	25.604	24.53	24.779				
59	3 node Wb	8.977	8.977	8.977					
60	9 node Audio	47.15633	49.259	46.172	46.038				
61	9 node Wb	10.479	10.479	10.479	10.479				
62									
63	**Wb + Video (4 fps) + Audio (14.4 kbps)**	Avg Delay							
64	3 node	1.66	1.539	1.881	1.593	1.901	1.735	1.311	
65	3 node Wb	9.017	9.017	9.017					
66	9 node	35.50033	36.337	34.396	35.693	36.845	34.319	35.412	
67	9 node Wb	11.521	11.521	11.521	11.521				
68									
69	3 node Audio	1.671	1.539	1.881	1.593				
70	3 node Video	1.649	1.901	1.735	1.311				
71	9 node Audio	35.47533	36.337	34.396	35.693				
72	9 node Video	35.52533	36.845	34.319	35.412				
73									
74	**Wb + Video (4 fps) + Audio (64 kbps)**	Avg Delay							
75	3 node	33.55083	34.705	32.67	33.477	35.114	32.273	33.066	
76	3 node Wb	10.401	10.401	10.401					
77	9 node	48.84817	55.509	45.268	48.593	53.506	45.825	44.388	
78	9 node Wb	12.378	12.378	12.378	12.378				
79									
80	3 node Audio	33.61733	34.705	32.67	33.477				
81	3 node Video	33.48433	35.114	32.273	33.066				
82	9 node Audio	49.79	55.509	45.268	48.593				
83	9 node Video	47.90633	53.506	45.825	44.388				
84									

Multicast, 128 kbps

	A	B	C	D	E	F	G	H	I
85	**Wb + Video (15 fps) + Audio (14.4 kbps)**	Avg Delay							
86	3 node	35.498	36.449	34.701	35.163	37.105	34.381	35.189	
87	3 node Wb	10.127	10.127	10.127					
88	9 node	46.96183	46.903	47.223	49.265	44.036	47.187	47.157	
89	9 node Wb	12.955	12.955	12.955	12.955				
90									
91	3 node Audio	35.43767	36.449	34.701	35.163				
92	3 node Video	35.55833	37.105	34.381	35.189				
93	9 node Audio	47.797	46.903	47.223	49.265				
94	9 node Video	46.12667	44.036	47.187	47.157				
95									
96	**Wb + Video (15 fps) + Audio (64 kbps)**	Avg Delay							
97	3 node	44.08217	47.457	42.035	44.239	47.416	40.827	42.519	
98	3 node Wb	13.227	13.227	13.227					
99	9 node	49.81467	57.499	45.4	49.709	59.728	41.298	45.254	
100	9 node Wb	17.605	17.605	17.605	17.605				
101									
102	3 node Audio	44.577	47.457	42.035	44.239				
103	3 node Video	43.58733	47.416	40.827	42.519				
104	9 node Audio	50.86933	57.499	45.4	49.709				
105	9 node Video	48.76	59.728	41.298	45.254				

Multicast + 384 kbps							
Text Chat	Avg Delay						
3 node	0.026333	0.033	0.023	0.023			
9 node	0.054	0.033	0.085	0.044			
Audio (14.4 kbps)	Avg Delay						
3 node	0.088	0.0755	0.113	0.0755			
9 node	0.215333	0.153	0.303	0.19			
Audio (64 kbps)	Avg Delay						
3 node	0.387667	0.333	0.5	0.33			
9 node	18.195	17.917	18.584	18.084			
Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.203167	0.233	0.271	0.233	0.143	0.196	0.143
9 node	0.5135	0.649	0.777	0.242	0.31	0.401	0.702
3 node Audio	0.245667	0.233	0.271	0.233			
3 node Video	0.160667	0.143	0.196	0.143			
9 node Audio	0.556	0.649	0.777	0.242			
9 node Video	0.471	0.31	0.401	0.702			
Video (4 fps) + Audio (64 kbps)	Avg Delay						
3 node	0.4185	0.492	0.658	0.492	0.272	0.325	0.272
9 node	24.30217	24.81	24.554	24.256	24.232	23.182	24.779
3 node Audio	0.547333	0.492	0.658	0.492			
3 node Video	0.289667	0.272	0.325	0.272			
9 node Audio	24.54	24.81	24.554	24.256			
9 node Video	24.06433	24.232	23.182	24.779			
Video (15 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.591167	0.67	0.707	0.67	0.434	0.632	0.434
9 node	27.86183	28.345	28.569	26.826	27.289	27.705	28.437
3 node Audio	0.682333	0.67	0.707	0.67			
3 node Video	0.5	0.434	0.632	0.434			
9 node Audio	27.91333	28.345	28.569	26.826			
9 node Video	27.81033	27.289	27.705	28.437			

Multicast, 384 kbps

Video (15 fps) + Audio (64 kbps)	Avg Delay						
3 node	5.815833	5.941	6.108	5.941	5.569	5.767	5.569
9 node	37.32967	37.549	36.975	36.944	37.541	37.222	37.747
3 node Audio	5.996667	5.941	6.108	5.941			
3 node Video	5.635	5.569	5.767	5.569			
9 node Audio	37.156	37.549	36.975	36.944			
9 node Video	37.50333	37.541	37.222	37.747			
Wb + Audio (14.4 kbps)	Avg Delay						
3 node Audio	0.124	0.149	0.114	0.109			
3 node Wb	2.983	2.983	2.983				
9 node Audio	0.283667	0.265	0.317	0.269			
9 node Wb	2.985	2.985	2.985	2.985			
Wb + Audio (64 kbps)	Avg Delay						
3 node Audio	0.437333	0.459	0.472	0.381			
3 node Wb	2.983	2.983	2.983				
9 node Audio	19.83367	19.713	19.903	19.885			
9 node Wb	2.994	2.994	2.994	2.994			
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.235167	0.192	0.237	0.271	0.331	0.199	0.181
3 node Wb	2.983	2.983	2.983				
9 node	0.5565	0.269	0.58	0.859	0.79	0.327	0.514
9 node Wb	3.216	3.216	3.216	3.216			
3 node Audio	0.233333	0.192	0.237	0.271			
3 node Video	0.237	0.331	0.199	0.181			
9 node Audio	0.569333	0.269	0.58	0.859			
9 node Video	0.543667	0.79	0.327	0.514			
Wb + Video (4 fps) + Audio (64 kbps)	Avg Delay						
3 node	0.515833	0.521	0.649	0.547	0.731	0.324	0.323
3 node Wb	2.983	2.983	2.983				
9 node	27.72883	27.591	27.959	28.393	27.991	27.391	27.048
9 node Wb	3.469	3.469	3.469	3.469			
3 node Audio	0.572333	0.521	0.649	0.547			
3 node Video	0.459333	0.731	0.324	0.323			
9 node Audio	27.981	27.591	27.959	28.393			
9 node Video	27.47667	27.991	27.391	27.048			

Multicast, 384 kbps

Wb + Video (15 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.580333	0.363	0.572	0.733	0.784	0.532	0.498
3 node Wb	2.983	2.983	2.983				
9 node	29.24933	28.811	29.198	29.818	29.666	28.898	29.105
9 node Wb	3.613	3.613	3.613	3.613			
3 node Audio	0.556	0.363	0.572	0.733			
3 node Video	0.604667	0.784	0.532	0.498			
9 node Audio	29.27567	28.811	29.198	29.818			
9 node Video	29.223	29.666	28.898	29.105			
Wb + Video (15 fps) + Audio (64 kbps)	Avg Delay						
3 node	8.023	7.759	8.451	8.064	7.959	8.212	7.693
3 node Wb	3.221	3.221	3.221				
9 node	36.7775	36.956	36.394	37.104	37.664	36.703	35.844
9 node Wb	4.776	4.776	4.776	4.776			
3 node Audio	8.091333	7.759	8.451	8.064			
3 node Video	7.954667	7.959	8.212	7.693			
9 node Audio	36.818	36.956	36.394	37.104			
9 node Video	36.737	37.664	36.703	35.844			

2, 3, 6, 9 Node Runs								
Unicast 128								
	Avg Delay							
Video (4 fps) + Audio (14.4 kbps)								
2 node	0.476	0.385	0.544	0.544	0.431			
3 node	5.798833333							
6 node	38.23333333	39.692	36.813	38.378	39.348	37.263	37.906	
9 node	46.11216667							
2 node Audio		0.385	0.544					
2 node Video		0.544	0.431					
6 node Audio		39.692	36.813	38.378				
6 node Video		39.348	37.263	37.906				
Wb + Audio (14.4 kbps)								
2 node Audio	0.645	0.751	0.539					
2 node Wb	8.95							
3 node Audio	1.258333333							
3 node Wb	11.1895							
6 node Audio	25.376	33.629	12.265	30.234				
6 node Wb	20.6715	27.303	14.04					
9 node Audio	51.54333333							
9 node Wb	37.08933333							
Wb + Video (4 fps) + Audio (14.4 kbps)								
2 node	1.07525	1.256	1.038	1.084	0.923			
2 node Wb	9.111							
3 node	15.63583333							
3 node Wb	11.654							
6 node	54.36666667	69.123	42.36	51.966	68.842	42.202	51.707	
6 node Wb	35.9815	48.635	23.328					
9 node	69.94566667							
9 node Wb	67.849							
2 node Audio		1.256	1.038					
2 node Video		1.084	0.923					
6 node Audio		69.123	42.36	51.966				
6 node Video		68.842	42.202	51.707				

Unicast 256								
	Avg Delay							
Video (4 fps) + Audio (14.4 kbps)								
2 node	0.23925	0.194	0.273	0.273	0.217			
3 node	0.408333333	0.329	0.465	0.488	0.408	0.408	0.352	
6 node	17.64633333	18.153	17.153	17.735	17.951	17.331	17.555	
9 node	34.008	35.123	33.256	33.829	34.819	33.481	33.54	
2 node Audio		0.194	0.273					
2 node Video		0.273	0.217					
6 node Audio		18.153	17.153	17.735				
6 node Video		17.951	17.331	17.555				
Wb + Audio (14.4 kbps)	Avg Delay							
2 node Audio	0.2165	0.248	0.185					
2 node Wb	4.478							
3 node Audio	0.36	0.462	0.288	0.33				
3 node Wb	5.5965	6.715	4.478					
6 node Audio	1.575	2.168	0.462	2.095				
6 node Wb	10.2305	13.69	6.771					
9 node Audio	10.40666667	15.305	0.833	15.082				
9 node Wb	13.89566667	20.858	7.027	13.802				
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay							
2 node	0.34325	0.412	0.353	0.313	0.295			
2 node Wb	4.558							
3 node	0.622333333	0.639	0.643	0.765	0.538	0.513	0.636	
3 node Wb	5.7875	4.646	6.929					
6 node	25.62966667	30.284	19.211	27.431	30.196	19.099	27.557	
6 node Wb	11.392	15.126	7.658					
9 node	45.53333333	55.675	35.502	45.182	55.489	35.366	45.986	
9 node Wb	21.684	32.861	10.502	21.689				
2 node Audio		0.412	0.353					
2 node Video		0.313	0.295					
6 node Audio		30.284	19.211	27.431				
6 node Video		30.196	19.099	27.557				

Unicast 384								
Video (4 fps) + Audio (14.4 kbps)	Avg Delay							
2 node	0.15975	0.129	0.182	0.183	0.145			
3 node	0.272833333							
6 node	0.7395	0.905	0.491	0.905	0.762	0.597	0.777	
9 node	20.4265							
2 node Audio (Runs 14b, 18b, 20b)		0.129	0.182					
2 node Video		0.183	0.145					
6 node Audio		0.905	0.491	0.905				
6 node Video		0.762	0.597	0.777				
Wb + Audio (14.4 kbps)	Avg Delay							
2 node Audio	0.1275	0.142	0.113					
2 node Wb	2.985							
3 node Audio	0.208							
3 node Wb	3.731							
6 node Audio	0.687	0.906	0.288	0.867				
6 node Wb	6.892	9.103	4.681					
9 node Audio	1.788333333							
9 node Wb	9.230666667							
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay							
2 node	0.20825	0.25	0.219	0.183	0.181			
2 node Wb	3.04							
3 node	0.3465							
3 node Wb	3.8565							
6 node	2.986	4.181	0.711	4.18	4.111	0.662	4.071	
6 node Wb	7.0655	9.186	4.945					
9 node	28.55033333							
9 node Wb	11.164							
2 node Audio		0.25	0.219					
2 node Video		0.183	0.181					
6 node Audio		4.181	0.711	4.18				
6 node Video		4.111	0.662	4.071				

Multicast 128									
Video (4 fps) + Audio (14.4 kbps)	Avg Delay								
2 node	0.4855	0.542	0.542	0.429	0.429				
3 node	0.609833333								
6 node	21.3625	21.484	21.681	21.023	21.076	21.35	21.561		
9 node	31.6245								
2 node Audio (Runs 914, 918, 920)		0.542	0.542						
2 node Video		0.429	0.429						
6 node Audio		21.484	21.681	21.023					
6 node Video		21.076	21.35	21.561					
Wb + Audio (14.4 kbps)	Avg Delay								
2 node Audio	0.6325	0.739	0.526						
2 node Wb	8.95								
3 node Audio	0.613666667								
3 node Wb	8.95								
6 node Audio	0.930666667	0.994	0.972	0.826					
6 node Wb	9.041	9.041	9.041						
9 node Audio	6.906333333								
9 node Wb	9.378								
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay								
2 node	1.08675	1.115	1.037	1.276	0.919				
2 node Wb	8.95								
3 node	1.66								
3 node Wb	9.017								
6 node	25.60733333	25.649	25.255	26.067	26.642	24.612	25.419		
6 node Wb	10.166	10.166	10.166						
9 node	35.50033333								
9 node Wb	11.521								
2 node Audio		1.115	1.037						
2 node Video		1.276	0.919						
6 node Audio		25.649	25.255	26.067					
6 node Video		26.642	24.612	25.419					

Multicast 256	Avg Delay							
Video (4 fps) + Audio (14.4 kbps)								
2 node	0.243	0.271	0.271	0.215	0.215			
3 node	0.305	0.35	0.406	0.35	0.215	0.294	0.215	
6 node	0.496666667	0.646	0.758	0.249	0.273	0.408	0.646	
9 node	10.10816667	10.306	10.484	9.708	9.8	9.937	10.414	
2 node Audio		0.271	0.271					
2 node Video		0.215	0.215					
6 node Audio		0.646	0.758	0.249				
6 node Video		0.273	0.408	0.646				
Wb + Audio (14.4 kbps)	Avg Delay							
2 node Audio	0.2105	0.242	0.179					
2 node Wb	4.476							
3 node Audio	0.206333333	0.243	0.195	0.181				
3 node Wb	4.476	4.476	4.476					
6 node Audio	0.29	0.304	0.316	0.25				
6 node Wb	4.523	4.523	4.523					
9 node Audio	0.454666667	0.427	0.5	0.437				
9 node Wb	4.691	4.691	4.691	4.691				
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay							
2 node	0.34625	0.331	0.351	0.41	0.293			
2 node Wb	4.476							
3 node	0.384833333	0.337	0.376	0.435	0.543	0.319	0.299	
3 node Wb	4.509	4.509	4.509					
6 node	0.704666667	0.453	0.761	0.956	0.952	0.459	0.647	
6 node Wb	4.917	4.917	4.917					
9 node	12.53466667	12.268	12.484	12.927	12.91	12.204	12.415	
9 node Wb	4.636	4.598	4.655	4.655				
2 node Audio		0.331	0.351					
2 node Video		0.41	0.293					
6 node Audio		0.453	0.761	0.956				
6 node Video		0.952	0.459	0.647				

Multicast 384								
Video (4 fps) + Audio (14.4 kbps)	Avg Delay							
2 node	0.162	0.181	0.181	0.143	0.143			
3 node	0.203166667							
6 node	0.331833333	0.431	0.506	0.167	0.183	0.273	0.431	
9 node	0.5135							
2 node Audio		0.181	0.181					
2 node Video		0.143	0.143					
6 node audio		0.431	0.506	0.167				
6 node video		0.183	0.273	0.431				
Wb + Audio (14.4 kbps)	Avg Delay							
2 node Audio	0.1225	0.137	0.108					
2 node Wb	2.983							
3 node Audio	0.124							
3 node Wb	2.983							
6 node Audio	0.183	0.195	0.2	0.154				
6 node Wb	2.985	2.985	2.985					
9 node Audio	0.283666667							
9 node Wb	2.985							
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay							
2 node	0.20825	0.192	0.217	0.245	0.179			
2 node Wb	2.983							
3 node	0.235166667							
3 node Wb	2.983							
6 node	0.380833333	0.2	0.406	0.553	0.566	0.21	0.35	
6 node Wb	2.985	2.985	2.985					
9 node	0.5565							
9 node Wb	3.216							
2 node Audio		0.192	0.217					
2 node Video		0.245	0.179					
6 node Audio		0.2	0.406	0.553				
6 node Video		0.566	0.21	0.35				

Satellite as multicast router							
******* 128 kbps							
Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.784333	0.941	0.944	0.829	0.715	0.719	0.558
3 node Audio		0.941	0.944	0.829			
3 node Video		0.715	0.719	0.558			
Wb + Audio (14.4 kbps)	Avg Delay						
3 node Audio	0.872667	1.097	0.727	0.794			
3 node Wb	9.193	9.193	9.193				
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	1.820333	1.669	2.107	1.79	1.978	1.891	1.487
3 node Wb	9.193	9.193	9.193				
******* 256 kbps							
Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.589333	0.738	0.738	0.618	0.52	0.521	0.401
3 node Audio		0.738	0.738	0.618			
3 node Video		0.52	0.521	0.401			
Wb + Audio (14.4 kbps)	Avg Delay						
3 node Audio	0.484333	0.596	0.43	0.427			
3 node Wb	4.716	4.716	4.716				
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.633667	0.508	0.761	0.718	0.76	0.551	0.504
3 node Wb	4.7985	4.798	4.799				
******* 384 kbps							
Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.539667	0.692	0.693	0.572	0.466	0.468	0.347
3 node Audio		0.692	0.693	0.572			
3 node Video		0.466	0.468	0.347			
Wb + Audio (14.4 kbps)	Avg Delay						
3 node Audio	0.406	0.493	0.373	0.352			
3 node Wb	3.23	3.23	3.23				
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.529667	0.383	0.688	0.615	0.631	0.468	0.393
3 node Wb	3.226	3.226	3.226				

Multicast router ashore							
****** 128 kbps							
Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	1.313667	1.649	1.539	1.539	1.281	0.936	0.938
3 node Audio		1.649	1.539	1.539			
3 node Video		1.281	0.936	0.938			
Wb + Audio (14.4 kbps)	Avg Delay						
3 node Audio	1.138	1.356	1.001	1.057			
3 node Wb	9.588	9.588	9.588				
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	9.054833	8.75	9.073	9.584	9.175	8.639	9.108
3 node Wb	9.746	9.746	9.746				
******* 256 kbps							
Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	1.044833	1.338	1.338	1.192	0.879	0.881	0.641
3 node Audio		1.338	1.338	1.192			
3 node Video		0.879	0.881	0.641			
Wb + Audio (14.4 kbps)	Avg Delay						
3 node Audio	0.743	0.905	0.656	0.668			
3 node Wb	5.016	5.016	5.016				
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	7.285167	6.873	7.408	7.764	7.353	6.938	7.375
3 node Wb	5.039	5.039	5.039				
******* 384 kbps							
Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	0.992	1.292	1.293	1.128	0.824	0.828	0.587
3 node Audio		1.292	1.293	1.128			
3 node Video		0.824	0.828	0.587			
Wb + Audio (14.4 kbps)	Avg Delay						
3 node Audio	0.660667	0.744	0.655	0.583			
3 node Wb	3.529	3.529	3.529				
Wb + Video (4 fps) + Audio (14.4 kbps)	Avg Delay						
3 node	6.745	6.534	7.059	6.827	6.955	6.666	6.429
3 node Wb	3.582	3.582	3.582				

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